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Crop Residue Management To Reduce Erosion and Improve Soil Quality

Southern Great Plains





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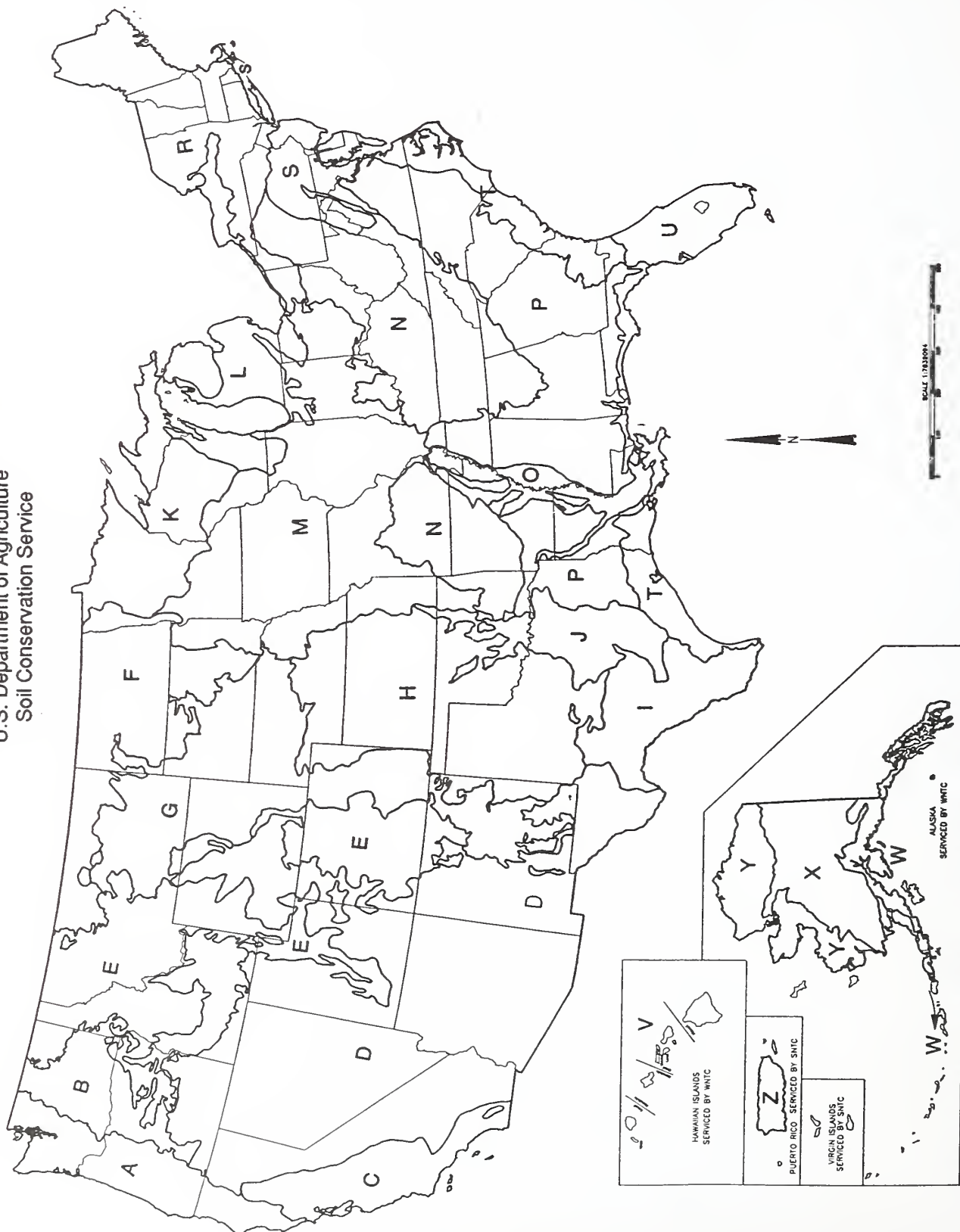
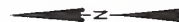
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Crop Residue Management Land Resource Regions of the United States

U.S. Department of Agriculture
Soil Conservation Service

Resource Regions and Areas
as of January 1984
Land Resource Regions (LRR)

- A** NW Forest, Forage and Specialty Crops
- B** NW Wheat and Range
- C** California Subtropical Fruit, Truck and Specialty Crops
- D** W. Range and Irrigated
- E** Rocky Mtn. Range and Forest
- F** N. Great Plains Spring Wheat
- G** W. Great Plains Range and Irrigated
- H** C. Great Plains Winter Wheat and Range
- I** SW Plateaus and Plains Range and Cotton
- J** SW Prairies Cotton and Forage
- K** N. Lake State Forest and Forage
- L** Lake States Fruit, Truck and Dairy
- M** Central Feed Grains and Livestock
- N** East and Central Farming and Forest
- O** Miss. Delta Cotton and Feed Grains
- P** S. Atlantic and Gulf Slope Cash Crops, Forest and Livestock
- R** NE Forage and Forest
- S** N. Atlantic Slope Diversified Farming
- T** Atlantic and Gulf Coast Lowland Forest and Crop
- U** Florida Subtropical Fruit, Truck and Range
- V** Hawaii
- W** S. Alaska
- X** Interior Alaska
- Y** Arctic and W. Alaska
- Z** Caribbean Area



Source: Map prepared using automated map construction, Albers equal area projection, National Cartography and Geographic Information System Center, Fort Worth, Texas 1983.

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Southern Great Plains

B.A. Stewart and W.C. Moldenhauer, Editors

Abstract

B.A. Stewart, and W.C. Moldenhauer, eds. 1994. *Crop Residue Management To Reduce Erosion and Improve Soil Quality: Southern Great Plains*. U.S. Department of Agriculture, Agricultural Research Service, CRR-37, 76 pp.

Leaving crop residue on the soil surface has a number of clear advantages over tillage that leaves the soil surface bare. Most obvious is the greatly reduced erosion from wind and water. Other advantages include increased yields from conserved water, lower soil temperatures, increased soil organic matter levels, and in many cases reduced requirements of time, labor, and fuel. Mandated conservation compliance by 1995 is an additional incentive for farmers to adopt crop residue management.

This is one of six regional publications that assemble research results and experiences for use by farmers and their advisers as they consider the factors involved in changing from full tillage to a system of crop residue management.

Keywords: Agricultural economics, conservation tillage, crop rotation, farming methods, erosion, mulch tillage, no-tillage, nutrient cycling, pest management, raindrop erosion, ridge tillage, soil compaction, soil conservation, soil erosion, surface residue tillage, sweep tillage, tillage, water conservation, wind erosion

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While supplies last, single copies of this publication may be obtained at no cost from a local Soil Conservation Service District office.

Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; telephone (703) 487-4650.

Copies of the five other regional reports on *Crop Residue Management To Reduce Erosion and Improve Soil Quality* are available for the cost of shipping and handling from the Conservation Technology Information Center, 1220 Potter Drive, Room 170, West Lafayette, IN 47906; telephone (317) 494-9555, FAX (317) 494-5969. The other regions are Northern Great Plains, Southeast, Appalachia and Northeast, Northwest, and North Central.

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Contents

Contributors.....	v
-------------------	---

<u>1</u> Introduction: Why the Emphasis on Crop Residue Management?	1
W.C. Moldenhauer and B.A. Stewart	

<u>2</u> Terminology	2
David L. Schertz and John Becherer	

<u>3</u> Climate, Soils, and Crops	3
J.L. Havlin and B.A. Stewart	

Climate	3
Soils	3
Crops and Crop Rotations	3

<u>4</u> Conservation Tillage Systems Used in the Southern Great Plains	8
Keith Vaughan, Neal Christensen, John E. Matocha, and Herb Sunderman	

Rio Grande Plain	8
Texas Coastal Bend	8
Southwest Texas	8
Eastern Great Plains	8
Central Region	9
Western Region	9
High Plains	9
Irrigated Regions	9

<u>5</u> Making the Transition from Clean Tillage to Crop Residue Management	14
O.R. Jones, J.H. Stiegler, D.W. Fryrear, and L.L. Dollar	

Gathering Information	14
Evaluation and Trial	14
Adoption of Crop Residue Management	14

<u>6</u> Soil-Water Conservation	16
P.W. Unger, E.G. Krenzer, Jr., and C.A. Norwood	

Combined Effects of Infiltration and Evaporation	16
Infiltration	17
Evaporation	17

<u>7</u> Measuring Surface Residue and Calculating Losses from Decomposition and Redistribution.....	21
Jean L. Steiner, Harry H. Schomberg, and J.E. Morrison, Jr.	

How Much Residue Is Necessary?	21
Decomposition Rate	22
Residue Redistribution	22
Principles of Residue Management	23

<u>8</u> Erosion Control with Sparse Residue	30
J.D. Bilbro, B.L. Harris, and O.R. Jones	

Soil Loss and Residue Type	30
Residue Quantities	30
Increasing Residue Production	30
Need for Complementary Practices	30

<u>9</u> Fertilizer Management	33
D.G. Westfall, W.R. Raun, J.L. Havlin, G.V. Johnson, J.E. Matocha, and F.M. Hons	

Soil Testing and Fertilizer Recommendations	33
Fertilizer Placement	34
Volatilization of Nitrogen Fertilizers	34
Managing Soil pH	34
Managing Manure	35
Strategies To Increase Fertilizer Efficiency	35
Preventing Nonpoint Pollution	35

<u>10</u> Effects of Crop Residue Management on Water Quality	37
S.J. Smith, A.N. Sharpley, and O.R. Jones	

Surface Water Quality	37
Groundwater Quality	37

<u>11</u> Soil Compaction and Bearing Strength	40
T.H. Dao, J.E. Morrison, Jr., and P.W. Unger	

Natural Consolidation	40
Compaction from Tillage and Wheel Traffic	40
Compaction in Mixed Cropping and Livestock Production Systems	41
Indications of and Remedies for Soil Compaction	42

12 Weed Management 45

Monte Toombs, R.L. Anderson, Paul Baumann, and
Wayne Keeling

Controlling Problem Weeds in Cotton 45
Controlling Problem Weeds in Grain Sorghum 45
Controlling Problem Weeds in Winter Wheat 46
Using Annual Winter Weeds as a Cover Crop 46

13 Insects and Diseases 48

Robert Burton, Charles Rush, and Phillip Sloderbeck

Altered Insect Habitats 48
Managing Insect Populations 48
Disease 49

14 Economics 51

Patricia E. Norris, Penelope L. Diebel, and
Arthur L. Stoecker

Off-Site Impacts 51
On-Site Impacts 51
Economic Analysis at the Farm Level 52

15 Long-Term Effects of Tillage and Crop
Residue Management 55

W.C. Moldenhauer, W.D. Kemper, and B.A. Stewart

The Beginnings of Soil Degradation 55
Effects of Reducing Tillage on Residual
Organic Matter 56
Effects of Increasing Surface Residues on Residual
Organic Matter 56
Effects of Leaving Crop Residue on the Surface 57
Reasons for Limited Tillage 59
Effects of Herbicides on the Environment 59

16 Management Options After Leaving the Conservation
Reserve Program 67

T.E. Schumacher, M.J. Lindstrom, M.L. Blecha, and
B.A. Stewart

The Conservation Reserve Program 67
How Grass Benefits Soil 67
Post-CRP Options 68
No-Till After CRP 69
Conservation Measures for Residue-Deficient Crops 70

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I Introduction: Why the Emphasis on Crop Residue Management?

W.C. Moldenhauer and B.A. Stewart

Soil erosion by wind or water degrades our soils. Besides outrightly removing material from the fertile topsoil, large windstorms or rainstorms selectively remove material high in organic matter and nutrients. The result is surface soil depleted of plant-available nutrients, high in density, and low in porosity and capacity for water intake.

Recognizing the rapidity with which U.S. soils are degrading—especially on the 143 million acres of highly erodible lands—Congress passed the Food Security Act in 1985 to conserve our soils and ensure adequate food supplies for future generations. **The act sets a deadline of December 31, 1994, for full implementation of plans to control erosion on highly erodible lands if farmers are to maintain their eligibility for U.S. Department of Agriculture (USDA) program benefits.** When presented with the broad spectrum of available technologies at USDA Soil Conservation Service (SCS) offices, fully three-fourths of farmers concluded that the most cost-effective means for controlling erosion on their highly erodible lands was to keep more crop residues on the soil surface.

Any tillage and planting system that leaves all or some portion of the previous crop's residue on the soil surface is described as crop residue management by SCS and the Conservation Technology Information Center, West Lafayette, IN. Surface residue cover is known to greatly reduce soil erosion, even though the percentage of surface residue required depends on the site and other conservation practices included in a total conservation plan. As residue cover approaches 100 percent, soil erosion approaches 0 percent; with 50 percent residue cover, erosion reduction is about 83 percent; when residue cover is 10 percent, erosion reduction is still about 30 percent.

Farmers' willingness to leave residue on the surface was greatly enhanced by the development of herbicides, which provided an alternative to tillage for controlling weeds. Efforts of equipment companies and innovative farmers in developing equipment to leave more residue on the surface and then to plant through it have facilitated the availability and use of crop residue management. The negative effects of crop residue, once looked on as far outweighing the benefits, are now seen as greatly overestimated, or solutions have been found to make the negative results manageable. As the scientific, industrial, and farm communities persistently address the problems and find solutions, they approach remaining problems more as challenges than as insurmountable disadvantages. This change of attitude has played a major role in accelerating the acceptance of crop residue management.

This publication is addressed to farmers, extension agents, conservation workers, and others with an interest in reducing soil erosion. It summarizes research and experience that show the potential benefits and problems related to decreasing tillage and leaving more residues on the soil surface. In the 15 chapters that follow, experts discuss the equipment, management practices, crop protection chemicals, crop rotations, cover crops, and cropping systems that will enable farmers to control erosion on their lands, so they are in Federal conservation compliance, while simultaneously optimizing their net returns and improving the environment and natural resources.

This is one of six regional reports. Some of the technology is suited specifically to the climate and soils of particular regions. However, due to recent and rapid development, not all of the potentially useful technologies have been tried in all regions. Consequently, some of the surface residue management technologies used in other regions and discussed in the other five reports may apply to the southern Great Plains. See the "Abstract" page in the front of the book for information about obtaining the other five reports.

Additional Sources

A number of other sources are available covering all aspects of crop residue management. These include farm magazines and publications of extension and research organizations, chemical and equipment companies, and organizations specializing in crop residue management.

Two particularly useful publications are listed following:

Hatfield, J.L., and B.A. Stewart, eds. 1994. *Crop residue management*. Lewis Publishers, Boca Raton, FL.

MidWest Plan Service. *Conservation tillage systems and management: crop residue management with no-till, ridge-till, mulch-till*. 1992. Midwest Plan Service Handbook 45. Available from the Midwest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080.

2 Terminology

David L. Schertz and John Becherer

In the early 1960's the terms *minimum tillage* and *reduced tillage* were used to denote fewer trips over the field. These fewer trips may or may not have left residue on the soil surface after planting or during the critical wind erosion period. The terms did not quantify the amount of surface residue left or any resulting reduction in erosion. The term *conservation tillage* also became popular. This term did imply that some surface residue was left but initially did not specify an amount.

In 1984, the Soil Conservation Service (SCS) defined *conservation tillage* as follows:

any tillage and planting system in which at least 30 percent of the soil surface is covered by plant residue after planting or at least 1,000 lb/acre of flat small-grain residue equivalent are left on the soil surface during the critical wind erosion period.

The objective of this conservation tillage was to leave surface residue to reduce the eroding forces of rain and wind. This definition remained standard through the early 1990's.

Conservation tillage comprises no-tillage (also called no-till), ridge tillage (ridge till), and mulch tillage (mulch till). They are defined by the Conservation Technology Information Center as follows:

- **No-tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is done in a narrow seedbed or slot made by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is done primarily with herbicides; cultivation may be used for emergency weed control.
- **Ridge tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is done in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is done with herbicides or cultivation or both. Ridges are rebuilt during cultivation.
- **Mulch tillage.** The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is done with herbicides or cultivation or both.

These definitions have gained considerable acceptance. Even so, some confusion remains as to the meaning of conservation tillage. Research shows that surface residue of less than 30 percent may reduce erosion considerably even

though, by definition, this amount is not considered conservation tillage. Most farmers chose to comply with the 1985 Food Security Act to maintain eligibility for USDA program benefits. Many farmers selected practices that left sufficient crop residue on the surface to meet conservation goals. However, some of these tillage practices left less than the amount required. Some people considered conservation tillage to mean only no-till. It became clear that standard terminology was needed to clarify the impacts of leaving all or a portion of the previous crop's residue on the soil surface. The term *crop residue management* evolved to address the benefits of surface residue in reducing soil erosion.

The practice of crop residue management encompasses an entire cropping year. (1) It begins with planting a crop that will meet a specified residue production goal. Cover crops can be used with low-residue cash crops. (2) An essential component is good distribution of residue at harvest. (3) It requires carefully planning the depth and speed of any tillage operation to maintain the desired amount of residue on the surface.

Crop residue management is defined as follows:

Any tillage and planting system that uses no-till, ridge tillage, mulch tillage, or another system designed to retain all or a portion of the previous crop's residue on the soil surface. The portion required depends on other conservation practices that may be included in the farmer's total conservation plan.

Throughout this publication, the terms *reduced tillage*, *minimum tillage*, *conservation tillage*, and *crop residue management* are used interchangeably. Each term refers to systems that leave all or a portion of the previous crop's residue on the soil surface to reduce soil erosion to an acceptable level.

3 Climate, Soils, and Crops

J.L. Havlin and B.A. Stewart

The southern Great Plains represents one of the most diverse regions in the United States. Extreme variations and differences exist in elevation, climate, soils, crops, and cropping systems. The region includes nearly all of Texas, Oklahoma, and Kansas, and the eastern parts of Colorado and New Mexico (see map inside back cover).

Climate

The wide ranges in elevation (0–7,800 ft) and latitude (27°–42° N) cause extreme differences in climate over the southern Great Plains (table 1). Average annual precipitation ranges from 46 inches in southeastern Texas (J–86) to 10 inches in southeastern Colorado (H–69). Snowfall accounts for approximately 20 percent or less of total precipitation in the northern areas, while contributing very little to total precipitation in the southern areas. Throughout the region, the year-to-year variability in precipitation is also extreme.

The majority of the precipitation is received during the spring and summer months (March–August) and coincides with most crops' need for water in the region. The distribution of annual rainfall and utilization by crops is illustrated in figure 1 for several locations. The data show that, although there are soil-profile water recharge periods, only a few areas have sufficient recharge to fill the holding capacity of the root zone and become surplus soil water. Soil-water deficits commonly occur during the growing season. These deficits are greatest in the western areas where rainfall is less and in southern areas where temperatures are higher.

Average annual temperatures range from 45 °F in the northern areas to 73 °F in the southern areas (table 1). The distribution of temperatures throughout the year at several locations is shown in figure 1. The number of frost-free days ranges from 120 days in northeastern Colorado to 330 days in southern Texas (table 1).

Figure 2 shows distribution of the wind erosion climatic factor *C*, which is related to wind velocity and other factors. These data indicate that wind velocity and wind erosion potential increase from east to west (annual precipitation decreases in the same direction), with the wind erosion potential being the greatest in western Kansas, western Oklahoma, western Texas, eastern Colorado and eastern New Mexico. Although water erosion occurs in these areas, soil losses from wind generally constitute the major portion of annual soil erosion losses from cultivated fields. Maintaining surface residue cover during winter and spring is essential for controlling soil erosion by wind.

Soils

The major land resource regions are the Central Great Plains Winter Wheat and Range Region (H), the Western Great Plains Range and Irrigated Region (G), the Southwest Plateaus and Plains Range and Cotton Region (I), and the Southwestern Prairies Cotton and Forage Region (J) (see map). The major land resource areas within each region are provided in table 1. Total land area is about 240 million acres.

The soils of the southern Great Plains region derive primarily from loess and are predominately loams, silt loams, and clay loams. The organic matter content ranges from 1.4 to 2.5 percent, with water-holding capacities ranging from 18 to 28 percent. The sand (Psamments) found in each state are generally deep with very low organic matter content and water-holding capacities. Many of the soils in the semiarid region are calcareous in the surface and subsoil. The Ustolls and Ustalfs in Texas and Oklahoma are predominately loams and clay loams, while the Vertisols of southern Texas have a high clay content.

Crops and Crop Rotations

About 55 million acres are used to produce dryland and irrigated crops, while pasture, range, and forest lands occupy 23, 112, and 13 million acres, respectively. Nearly 8 million acres are irrigated. The major crop—winter wheat—is produced on approximately 30 million acres. The majority of the wheat is produced under summer fallow in either a wheat-fallow (one crop in 2 years), or a wheat-grain sorghum-fallow rotation (two crops in 3 years). In south central Kansas and north central Oklahoma continuous winter wheat is produced on 3–4 million acres. Some of the winter wheat is produced under irrigation, but it is not as common as irrigated coarse-grain crops (corn and sorghum).

Approximately 6.5, 10.5, and 6.0 million acres of grain sorghum, hay, and cotton are grown. Kansas and Texas produce the majority of the sorghum; about 20 percent is irrigated. About 60 percent of the hay is produced in Texas and Kansas, and nearly 90 percent of the cotton is produced in Texas. The remaining major crops in the region are corn (4.5 million acres), soybeans (2.7 million acres), barley (0.9 million acres), oats (1.5 million acres), peanuts (0.4 million acres), rye (0.2 million acres), sunflowers (0.1 million acres), and drybeans (0.1 million acres).

The primary dryland crop rotation in areas where annual precipitation is less than 20–24 inches (western Kansas, western Oklahoma, eastern Colorado, eastern New Mexico, and northern and central Texas) is wheat-fallow or dryland sorghum produced in a fallow system. As precipitation increases, wheat-sorghum-fallow cropping systems are more common. Cotton, either continuous or in a rotation, is the dominant crop in the southern high plains and central regions of Texas. Under irrigation many producers raise continuous corn or sorghum. Some rotate these crops with alfalfa, wheat, drybeans, and other crops.

Table 1. Southern Great Plains: major land resource areas, acres, topography, primary crops, and climatic characteristics

Area*	Description	Acres (millions)	Elevation (ft)	Topography	Primary crops	Precip- itation (inches)	Aver. annual temp. (°F)	Frost-free days
G-67	Central High Plains	11.9	3600-5900	Undulating to rolling	Wheat, irrigated corn, sugar beets, alfalfa	13-17	45-50	120-180
G-69	Upper Arkansas Valley Rolling Plains	8.4	3600-6200	Undulating to rolling	Wheat, grain sorghum, irrigated crops	10-15	50	140-160
G-70	Pecos-Canadian Plains and Valleys	21.0	3900-7800	Gently sloping to rolling	Small grains, grain sorghum, beans	12-16	50-60	135-200
H-72	Central High Tableland	13.4	2600-3900	Nearly level to gently rolling	Wheat, grain sorghum, irrigated crops	16-21	50-57	140-185
H-73	Rolling Plains and Breaks	10.5	1600-2900	Undulating to rolling and hilly	Wheat, grain sorghum, corn	20-25	50-55	150-180
H-74	Central Kansas Sandstone Hills	3.0	1300-1600	Undulating to hilly	Wheat, grain sorghum, hay, corn	25-28	54-55	170-180
H-75	Central Loess Plains	3.9	1600-2000	Nearly level to gently rolling	Wheat, grain sorghum, hay, corn	25-30	50-57	160-190
H-76	Bluestem Hills	4.8	1000-1600	Gently sloping	Wheat, grain sorghum, hay	15-22	55-63	130-220
H-77	Southern High Plains	31.3	2600-6500	Gently sloping	Wheat, grain sorghum, cotton	15-22	55-63	130-220
H-78	Central Rolling Plains	32.2	1600-2900	Nearly level to gently sloping	Wheat, grain sorghum, cotton	20-30	57-64	185-230
H-79	Great Bend Sand Plains	2.7	1600-2600	Undulating to rolling	Wheat, grain sorghum, alfalfa	21-28	55-57	180-190
H-80A	Central Rolling Red Prairies	13.0	1000-1600	Undulating to gently rolling	Wheat, alfalfa, cotton, sorghum, peanuts	25-36	57-64	190-230

Area*	Description	Acres (millions)	Elevation (ft)	Topography	Primary crops	Precip- itation (inches)	Aver. annual temp. (°F)	Frost-free days
H-80B	Texas North Central Prairies	6.3	600-2300	Undulating divides and steep-sided valleys	Wheat, oats, cotton, grain sorghum	22-30	64-66	215-240
I-81	Edwards Plateau	23.9	600-3900	Narrow valleys with sloping to steep walls	Hay and small grains for grazing	15-30	64-68	230-270
I-82	Texas Central Basin	1.4	600-1200	Broad valleys with sloping walls	Sorghum, cotton, peanuts, grain for grazing	25-30	64-68	210-270
I-83A	Northern Rio Grand Plain	5.2	100-600	Nearly level with smooth hills and valleys	Sorghum, cotton, corn, grain for grazing	25-30	70-72	260-310
I-83B	Western Rio Grand Plain	5.8	200-1000	Gently undulating	Sorghum, small grain, cotton, pasture	17-21	70-72	260-290
I-83C	Central Rio Grand Plain	5.8	100-700	Gently undulating	Sorghum, cotton, grain for grazing	21-26	70-73	280-325
I-83D	Lower Rio Grand Plain	1.6	0-700	Nearly level	Irrigated cotton, sorghum, vegetables	17-28	72-73	300-330
J-84A	Cross Timbers	6.8	1000-1300	Nearly level to strongly rolling	Small grains, sorghum, cotton, hay	25-36	59-63	190-240
J-84B	West Cross Timbers	3.7	1000-1300	Nearly level to rolling	Peanuts, sorghum, small grains	25-35	63-66	225-240
J-84C	East Cross Timbers	1.4	600-700	Gently sloping to rolling	Peanuts, small grains, sorghum	35-40	63-66	225-250
J-85	Grand Prairie	7.8	600-1300	Gently rolling to hilly	Oats, wheat, sorghum, cotton, corn, hay	28-41	63-70	200-260
J-86	Texas Blackland Prairie	11.8	300-700	Nearly level to gently rolling	Cotton, grain sorghum, small grains, corn	30-46	63-70	230-280
J-87	Texas Claypan Area	3.3	100-700	Nearly level to sloping	Pasture, cotton, corn, peanuts, hay	30-43	64-72	240-280

* Major land resource area. See map inside back cover to find locations.

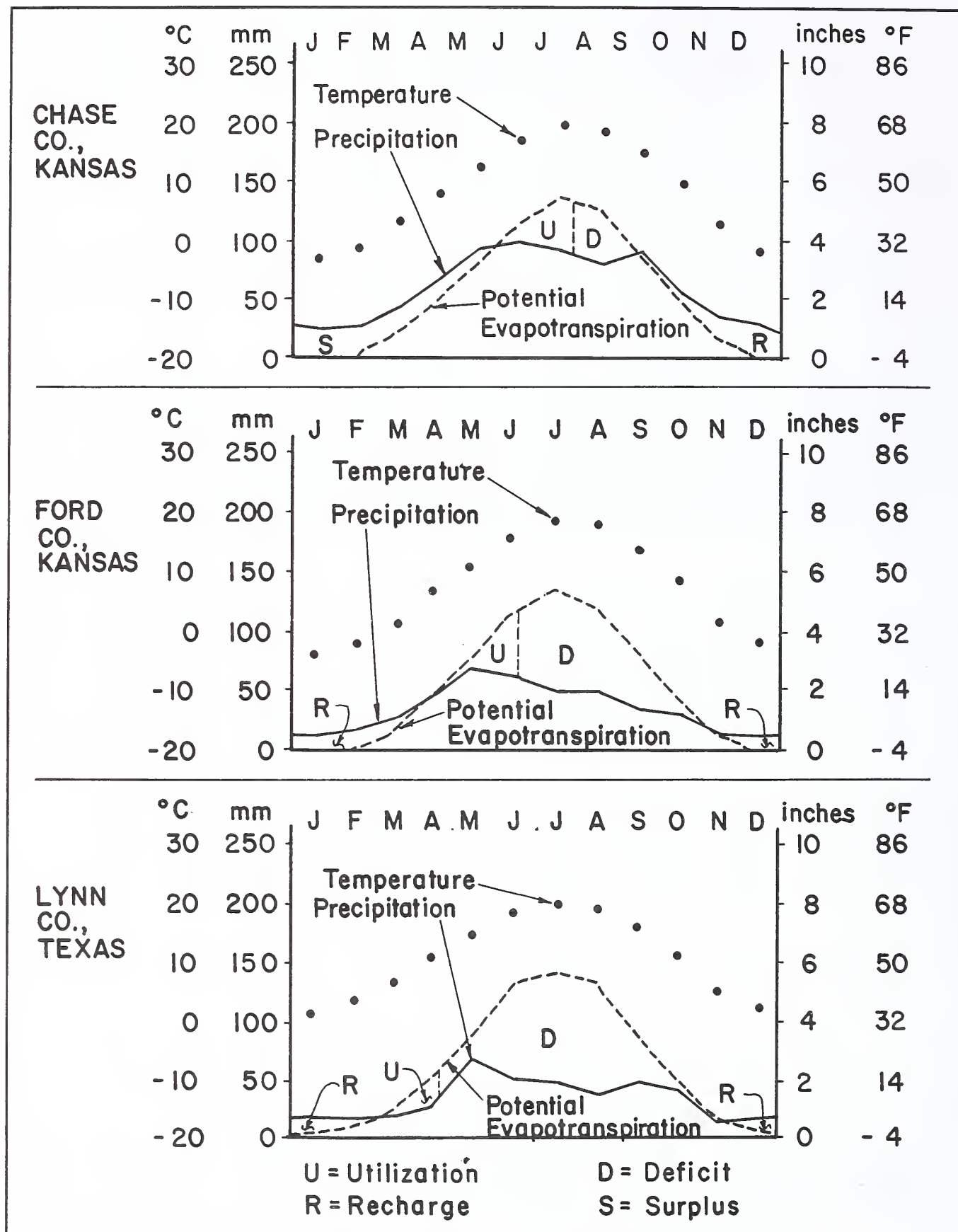


Figure 1. The distribution of temperature, rainfall, and potential evaporation at selected locations in the southern Great Plains. When precipitation exceeds evaporation, soil water recharge (R) occurs; alternatively, when evaporation exceeds precipitation, soil water deficit (D) exists. Soil water utilization (U) is the quantity of water crops use equivalent to soil water recharge. S indicates a surplus of water that goes to the aquifer.

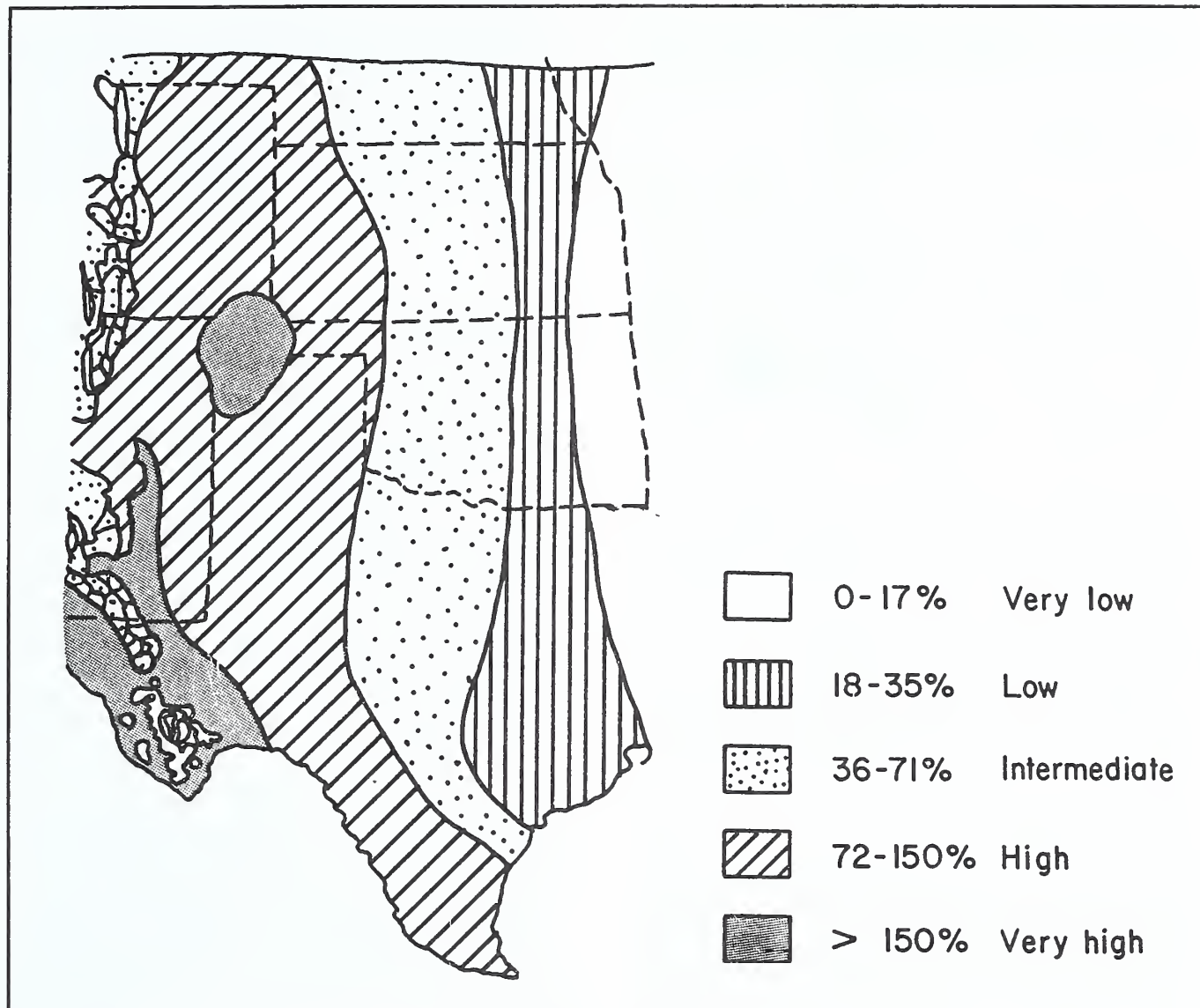


Figure 2. Wind-erosion climatic factor C, as a percentage of the value at Garden City, KS

4 Conservation Tillage Systems Used in the Southern Great Plains

*Keith Vaughan, Neal Christensen,
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Amounts of precipitation and lengths of growing season change tremendously from the southern coast of Texas to the northeastern corner of Colorado. Traditional cropping and tillage systems have evolved in the region in response to these climatic features. Continuous cropping in the southern and eastern parts of the region gradually changes to fallow rotations in the west and north where water is the primary factor limiting the use of other systems.

Relatively few acres are devoted to crop residue management systems in the five-state region (tables 2-4). The 1992 National Crop Residue Management Survey (Conservation Technology Information Center 1992) shows that of the 54,591,299 cropland acres within the region only 12,668,392 acres or 23 percent are farmed with a conservation tillage system. An additional 17,075,965 acres or 31 percent are farmed with 15-30 percent residue coverage. In the area south of a line from San Angelo to Temple, TX, a majority of the cropland acreage is under a conventional, or clean tillage, system.

Rio Grande Plain

Conservation tillage using ridge tillage is increasing in the Rio Grande Plain region for irrigated row crops in the lower valley and dryland row crops in the upper valley. Basically, the tillage operations are to shred, double disc, bed, apply a contact herbicide such as glyphosate or paraquat to control weeds, inject fertilizer into the bed in the fall, run middles with a rolling cultivator or large sweeps once or twice before planting, plant, and cultivate two times. The principal row crops grown in this system are cotton, grain sorghum, and corn. Vegetable acreage fluctuates and generally involves intensive tillage operations.

Texas Coastal Bend

In the Texas Coastal Bend region, crop residue management is slowly increasing. Major crops in this predominantly dryland farming region are grain sorghum, corn, and cotton. Tillage to achieve a clean seedbed is traditional and deeply entrenched. When practiced, conservation tillage is usually limited to the finer textured soils. A crop residue management system developed at the Texas A&M Research and Extension Center, in Corpus Christi, is slowly being adopted by area producers. Cultural practices in this system include the following operations:

- disc stubble,
- undercut roots at a depth of 3-5 inches with sweeps or root plow and form a low-profile ridge or bed in the same operation,
- apply appropriate herbicides for fall and winter weed control, as needed (usually two applications),
- inject fertilizer into the beds and till in same operation, and
- plant and cultivate once.

In a cotton production system, one or two additional tillage operations may be done. Depending upon the weather (primarily rainfall), some years may require two and three cultivations to control weeds in the spring.

In contrast to the crop residue management system, the conventional tillage system requires approximately 9 or 10 tillage operations. The operations usually involved are double disc stubble (shred cotton stalks before discing), cultivate with a field cultivator two or three times, shape beds and run middles once or twice, inject fertilizer into the bed using either liquid or anhydrous ammonia, plant to moisture (plant in moist soil), cultivate early (2-3 weeks following plant emergence), and cultivate later one or more times for weed control.

Southwest Texas

In southwest Texas a sizeable portion of the cropland is irrigated, with corn, cotton, vegetables, and peanuts being the principal crops. Major dryland crops include grain sorghum and small grains. Conventional tillage operations for corn and sorghum include two discings of the stubble, row listing and bed shaping, furrow plowout, planting, and one or two postplant cultivations for weed control. Tillage operations for cotton are similar to those for corn and sorghum, with the exception that planting is done on raised beds instead of in furrows and tillage is needed to incorporate herbicides. Small grains are usually drilled into land that has been chiseled or disced once. Peanuts are planted in shaped, ridge-till beds that are disced twice before shaping again. Approximately 5 percent of the peanut acreage is planted in a strip-till system to prevent wind erosion. Wheat is the most common crop used, with peanuts in the alternate strips.

Eastern Great Plains

In the eastern portion of the Great Plains, abundant crop residue has resulted in the perception that more aggressive tillage systems are needed to reduce the amounts to plantable levels. Although the moldboard plow is giving way to tandem discs and chisel plows for primary tillage, interest and opportunities exist for still less tillage. Limited amounts of in-season cultivation are practiced and herbicides provide most of the weed control. Principal field

crops include corn, soybeans, grain sorghum, small grains, and forages. Relay cropping, where soybeans are planted into growing winter wheat, is sometimes practiced, as is double cropping of wheat and soybeans. Since time constraints offer few opportunities for tillage in these double-crop systems, there's ample incentive for less tillage and even no-till systems.

Central Region

In central Texas, Oklahoma, and Kansas, decreasing rainfall and higher wind speeds require cropping systems and tillage practices that conserve moisture and prevent wind erosion. Cotton and peanuts are grown in the southern part of this area, and conventional tillage systems are usually used in order to incorporate herbicides for effective weed control. An increasing amount of cotton acreage is planted in a small-grain cover crop, with strip tillage used to incorporate herbicides banded over the cotton row. This no-till cover-crop system also works well under a pivot sprinkler system where chemigation can be used to apply and activate herbicides.

Where continuous wheat is grown, a mulch-tillage system is used. Typically, this involves using sweeps or a tandem disc shortly after harvest and either sweeps or chisels one or two more times during the summer to control weeds and apply anhydrous ammonia. Herbicides are increasingly being used as substitutes for tillage in this type of system.

Western Region

Sweeps are the predominate dryland tillage implement in the western part of the southern Great Plains. A common practice in the western portion of the area where wheat-fallow dominates is to perform one or two sweep operations after wheat harvest and before winter, with the first for weed control and to cover any wheat grains left from the harvesting operation and the second, if used, to control volunteer wheat. Two or three more sweep operations are performed the following spring and summer. A finishing operation with something like a rod weeder is performed just ahead of wheat seeding.

High Plains

In the high plains of eastern New Mexico, western Texas, southwestern Kansas, and Oklahoma a wheat-sorghum-fallow rotation is common. Here conservation tillage includes a combination of sweep tillage and herbicides. Herbicides are used when going from wheat to sorghum, with the sorghum planted into the wheat residue using a no-till system. When going from sorghum to wheat, the blade plow is used for weed control from April through July. Before planting wheat, weed control is done with herbicides, which leave the seedbed in a firm condition. A similar stubble-mulch system uses a blade plow (a v-shaped

blade more than 24 inches wide designed to operate at shallow depths) for weed control during the fallow periods. Primary tillage implements (such as disc or moldboard plow) that incorporate the residue are used infrequently.

In crop rotations including corn and grain sorghum, the degree of tillage depends on the rotation. These crops are often planted no-till following small grains or cotton. A ridge-tillage system is used following either corn or sorghum. When sorghum or corn follows peanuts or vegetables, a conventional tillage system is used or a small grain is planted as a cover crop. This cover crop is then killed in April, and corn or sorghum is planted no-till in the remaining vegetation.

In the drier regions, herbicides increasingly substitute for tillage in wheat-fallow and other crop-fallow rotations. Accompanying improvements in the efficiency with which the soil stores precipitation suggest that the traditional wheat-fallow, sorghum-fallow, and millet-fallow rotations may give way to more economically competitive and complex rotations that shorten or even eliminate the fallow periods. These rotations and the related economics may provide additional incentive or even dictate the practice of no-till. Sunflowers offer rotation alternatives but also challenge farmers to control wind erosion.

Irrigated Regions

Irrigated areas in western Kansas and eastern Colorado are devoted primarily to corn and occasionally to soybeans, grain sorghum, or winter wheat. Chiseling to depths of 12 or more inches is often used to increase the rate of water infiltration. In these areas, as in eastern Kansas, discs and chisel plows are the primary tillage tools with residual herbicides for in-season weed control. Other tillage operations, such as furrow diking, are being developed to complement the irrigation system.

Planting, fertilizing, and herbicide equipment has been developed for complete no-till systems, but acceptance has been slowed by the expense of herbicides. Likewise, ridge-tillage planting and cultivation equipment has been developed to handle the slowly decomposing residue in the semiarid western area, but adoption is slow and is limited to irrigated production in this region.

Reference

Conservation Technology Information Center. 1992. National crop residue management survey. National Association of Conservation Districts, West Lafayette, IN.

Table 2. Management systems used on major crops in southeast and southwest Texas

Crop	Conservation Tillage					% in conser- vation tillage
	No-till (acres)	Ridge- till (acres)	Mulch- till (acres)	Conven- tional (acres)	Strip tillage (acres)	
Southeast Texas*						
Grain sorghum	0	0	230,300	662,500	0	25.8
Corn	0	0	21,600	125,000	0	14.7
Cotton	0	0	151,000	400,600	0	27.4
Small grains	0	0	3,000	2,500	0	54.5
Soybeans	0	231	6,200	0	0	3.6
Peanuts	0	0	0	0	0	0.0
Sunflowers	0	0	0	0	0	0.0
Other	0	19,000	295,700	0	0	6.0
Southwest Texas†						
Grain sorghum	0	0	2,000	173,000	0	1.1
Corn	0	0	2,000	88,000	0	2.2
Cotton	0	0	1,000	24,000	0	4.0
Small grains	0	0	10,000	390,000	0	2.5
Soybeans	0	0	0	0	0	0.0
Peanuts	0	45,000	0	1,000	2,000	0.0
Sunflowers	0	0	0	0	0	0.0
Other	0	0	1,000	35,000	0	26.0

* Includes all counties south of Webb, McMullen, Live Oak, Bee, San Patricio, and Arkansas

† Includes 13 counties south and east of the San Angelo area

Table 3. Management systems used on major crops in Kansas

Crop	Conservation Tillage			Other Tillage Systems	
	No-till	Ridge tillage	Mulch tillage	15-30% residue	0-15% residue
	----- (% of crop's acreage) -----				
Corn*	9.1	7.3	29.8	25.1	28.6
Corn†	14.1	0.0	0.0	57.8	28.2
Small grains‡	2.8	0.3	26.0	38.1	32.8
Small grains§	0.9	0.1	22.3	34.0	42.7
Soybeans*	6.7	0.7	17.0	29.7	45.9
Soybeans†	18.3	0.4	15.3	21.1	45.0
Cotton	0.0	0.0	0.0	41.8	58.2
Grain sorghum*	5.7	1.2	24.6	31.5	37.1
Grain sorghum†	17.0	2.7	27.5	30.5	22.3
Forage crops	1.1		13.6	34.0	51.3
Other	5.3	0.0	20.5	37.3	37.0
Total percent	3.5	1.0	22.7	32.3	40.5

Source: Conservation Technology Information Center, December 10, 1992.

* Full season

† Double cropped

‡ Spring seeded

§ Fall seeded

Table 4. Management systems used on major crops in Oklahoma

Crop	Total acres	Conservation Tillage			Total conservation tillage	Other Tillage Practices		
		> 30% residue or 1,000 lb SGE*		Mulch till		15-30% residue		0-15% residue
		No-till	Ridge till			500-1,000 lb SGE*	< 500 lb SGE*	
Corn, full season	147,052	2,392 (1.63)	2,000 (1.36)	27,660 (18.81)	32,052 (21.80)	22,416 (15.24)	92,584 (62.96)	
Corn, double cropped	980	0	0	520 (53.06)	520 (53.06)	250 (25.51)	210 (21.43)	
Small grains, spring seeded	50,877	2,495 (4.90)	0	4,685 (9.21)	7,180 (14.11)	16,820 (33.06)	26,877 (52.83)	
Small grains, fall seeded	6,882,906	34,250 (0.50)	3,100 (0.05)	1,488,450 (21.63)	1,525,800 (22.17)	2,177,520 (31.64)	3,179,586 (46.20)	
Soybeans, full season	158,211	1,875 (1.19)	650 (0.41)	23,530 (14.87)	26,055 (16.47)	26,771 (16.92)	105,385 (66.61)	
Soybeans, double cropped	95,805	18,810 (19.63)	0	16,294 (17.01)	35,104 (36.64)	31,520 (32.90)	29,181 (30.46)	
Cotton	403,603	3,710 (0.92)	6,000 (1.49)	8,940 (2.22)	18,650 (4.62)	93,331 (23.12)	291,622 (72.25)	
Grain sorghum, full season	315,217	8,450 (2.68)	7,500 (2.38)	135,108 (42.86)	151,058 (47.92)	79,103 (25.09)	85,056 (26.98)	
Grain sorghum, double cropped	44,366	2,700 (6.09)	1,000 (2.25)	10,145 (22.87)	13,845 (31.21)	18,912 (42.63)	11,609 (26.17)	
Forage crops†	166,196	5,390 (3.24)	NA	13,846 (8.33)	19,236 (11.57)	47,899 (28.82)	99,061 (59.60)	
Other crops‡	389,703	15,000 (3.85)	660 (0.17)	66,140 (16.97)	81,800 (20.99)	111,044 (28.49)	196,859 (50.52)	
Total planted acres	8,654,916	95,072 (1.10)	20,910 (0.24)	1,795,318 (20.74)	1,911,300 (22.08)	2,625,586 (30.34)	4,118,030 (47.58)	

Crop	Total acres	Conservation Tillage			Total conservation tillage	Other Tillage Practices	
		> 30% residue or 1,000 lb SGE*				15-30% residue	0-15% residue
		No-till	Ridge till	Mulch till		500-1,000 lb SGE*	< 500 lb SGE*
Other noncropped acres							
Newly established permanent	142,314	47,481 (33.36)	NA	8,515 (5.98)	55,996 (39.35)	24,601 (17.29)	61,717 (43.37)
Fallow	330,000	33,330 (10.10)	NA	79,860 (24.20)	113,190 (34.30)	93,720 (28.40)	123,090 (37.30)
Conservation research program	1,148,956	NA	NA	NA	NA	NA	NA
Annual conservation uses	1,170,843	NA	NA	NA	NA	NA	NA

NOTE: Numbers in parentheses are percentages.

* SGE = small-grain equivalent

† Forage crops reported in seeding year only

‡ Other crops include vegetable and truck crops (peanuts, tobacco, etc.)

§ Annual conservation use includes cropland idled for government programs

5 Making the Transition from Clean Tillage to Crop Residue Management

O.R. Jones, J.H. Stiegler, D.W. Fryrear, and L.L. Dollar

Crop residue management has the potential to save "soil, oil, and toil" (Nowak 1983). In the southern Great Plains it can also save water—an extremely valuable resource. Why, then, isn't everyone using residue management technology? The probable answer is that traditional systems work well, provide a good bottom line, are low risk, and offer familiarity. Until conservation compliance on highly erodible lands came along, a farmer was not aware of an erosion problem unless the gully backed up into the field or the fence or road was buried by accumulating soil from wind erosion.

Today, the need to comply with conservation regulations, a tightening cost and price squeeze, and a new environmental awareness have many farmers and landlords looking at new or improved technology to solve actual or anticipated problems. On many, and maybe even most, farms in the southern Great Plains, crop residue management using mulch tillage, ridge tillage, or no-tillage can be an important part of an ethic to conserve soil and water resources and use them wisely.

Gathering Information

Once confronted with a soil or water conservation problem, farmers need accurate information in order to evaluate alternative management strategies, including residue management. Useful crop residue management information can be obtained from many sources, including the five companion regional crop residue management publications (see abstract page for ordering information); Soil and Water Conservation Districts; nearby offices of USDA agencies such as the Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), and the Agricultural Research Service; state extension services; university research stations; farm publications; and local agribusinesses such as equipment and chemical suppliers. In addition, associations and clearinghouses offer many special publications; see "Additional Sources" at the end of this chapter.

Industry, research facilities, and extension and USDA agencies can provide useful technology, but until this technology is integrated into a successful farming system, it cannot be completely evaluated. The ultimate integrator—and to many farmers the most credible source of information—is another farmer who is using the system successfully and has evaluated its advantages, disadvantages, and pitfalls. For those who are not well acquainted with these farmers, SCS district conservationists and conservation district leaders can help. Each farmer

should discover what is working in his or her own area, combine this knowledge with information gathered from other sources, and develop systems adapted to the individual farm situation. If SCS has identified farmland as highly erodible, farmers should contact their office to make sure their plans both achieve erosion control within regulations and maintain their eligibility for USDA support programs.

Evaluation and Trial

Having gathered sufficient information, a farmer moves into evaluation and trial, which calls for consideration of all alternatives and their benefits and problems. Leaving crop residue on the surface and reducing tillage affect a broad spectrum of factors that determine the quality and productivity of the soil. Therefore, landowners and operators should address some questions before adopting a new system. Which system will work best on my fields? How do I control cheat grass with no-tillage in annual wheat? Will I have to change crop rotations to switch to no-tillage? How can I direct seed cotton into a winter wheat cover crop killed with glyphosate? How do I apply fertilizer with no-tillage? How can I control root rot in a cotton-sorghum rotation without moldboarding?

Farmers can expect to encounter difficulty in generating this type of required information because of the numerous residue management systems. Detailed information from one system (mulch tillage with wheat-sorghum-fallow in the Texas Panhandle, for example) may not be transferable to another area or system (mulch tillage with annual wheat in central Oklahoma). Furthermore, as crops, soils, climate, or pest situations change, specific recommendations must also change.

If sufficient information is not available at the local extension or SCS office to enable realistic economic estimates or the proposed tillage system increases the risk of failure, then the proper decision is to reject the technology. If a proposed system offers a good bottom-line estimate and provides the required erosion protection, then the decision may be to try it on one field, perhaps using custom farming or renting or leasing equipment and putting off the modification or purchase of equipment until information from several seasons can be collected.

Adoption of Crop Residue Management

Residue management can take many forms, and some may not differ greatly from a system currently in use. Switching from moldboard plowing to chiseling and disking for land preparation or switching from disks to v-blades is not a big change. However, changing from these lower intensity tillage systems to no-tillage requires more attention to management and perhaps a longer planning period if persistent chemicals are used in rotations. Most growers opt for reduced-tillage systems, which may include no-tillage to

persistent chemicals are used in rotations. Most growers opt for reduced-tillage systems, which may include no-tillage to grow one crop in the rotation and limited tillage to grow the next crop. For example, in a dryland wheat-sorghum-fallow rotation in the Texas and Oklahoma Panhandles, herbicides are used to control weeds after wheat harvest and during the 11-month fallow, with direct seeding of sorghum into residues. No-tillage saves about 1 1/2 inches of soil water during fallow compared to v-blade sweeps. Pre- or postemergent chemicals are used to control weeds in sorghum. The sorghum stubble is left standing after harvest to capture snow and control wind erosion until the following spring and summer when v-blades are used to control weeds and prepare the seedbed prior to sowing winter wheat.

Adoption of residue management systems may necessitate a change in cropping rotation to grow high-residue-producing crops such as sorghum, corn, or small grains, which protect the soil so peanuts, cotton, or soybeans can be grown the following season. Continuous cropping with low-residue-producing crops (cotton, soybeans) is not compatible with residue management on highly erodible lands unless special management techniques such as strip cropping are used. In areas prone to wind erosion, one technique is to strip crop using permanent grass strips. Where irrigation is available or winter water supplies are adequate to grow a cover crop, the high-value crop can be planted directly into the killed cover crop.

As mentioned, crop residue management is not static. Just as changes are necessary with traditional systems, a residue management system must be adapted in response to changing crop and environmental conditions. The management decisions made during a wet year may not work during a dry year. Crop rotations, changing commodity prices, prices paid for inputs, pests, and chemical carryover can force alterations and modifications of the system. It is important, then, that the tillage system chosen be flexible enough to meet changing requirements and needs. Information about and assistance with the adopted program are available from the same sources that provided help during the information-gathering phase—the innovative farmer, the conservation professional, the agribusiness dealer, the association, the state and Federal office.

Reference

Nowak, Peter J. 1983. Obstacles to adoption of conservation tillage. *Journal of Soil and Water Conservation* 38:162–165.

Additional Sources

American Society of Agricultural Engineers, 2950 Niles Rd., St. Joseph, MI 48085; (616) 428–6324.

American Society of Agronomy, 677 South Segoe Rd., Madison, WI 53711; (608) 273–8080.

Conservation Technology Information Center, 1220 Potter Dr., Rm. 170, West Lafayette, IN 47906; (317) 494–9555.

Soil and Water Conservation Society, 7515 NE Ankeny Rd., Ankeny, IA 50021–9764; 1–800–843–7645 or (515) 289–2331.

6 Soil-Water Conservation

P.W. Unger, E.G. Krenzer, Jr., and C.A. Norwood

Limited precipitation is the major constraint to dryland crop production in the southern Great Plains, and for that reason increased soil-water storage is highly important. It is also important for irrigated crops, especially where water for irrigation is limited and expensive and where limited irrigation is practiced.

Researchers showed more than 50 years ago that crop residues left on the soil surface increased soil-water storage by promoting greater infiltration and by reducing evaporation. At that time, however, field crop production under high surface-residue conditions was not practical because suitable techniques were not yet available for controlling weeds, maintaining crop residues on the surface, and planting crops under high-residue conditions. The early research led, however, to development of stubble-mulch tillage, a form of crop residue management. Later, development of herbicides for controlling weeds during both fallow periods and crop-growing seasons contributed to development of other practices that retain crop residues on the surface. Today, some crop residue management systems frequently conserve more water both in dryland and irrigated agriculture than the use of conventional (clean) tillage.

Combined Effects of Infiltration and Evaporation

Storage of precipitation as soil water during noncropped periods generally increases as surface residue increases and results in greater crop yields (tables 5 and 6). Although the residue produced from dryland crops is often not adequate to greatly increase soil-water storage during fallow periods, even relatively small amounts when effectively managed improve water storage. For example, precipitation storage and wheat yields doubled by changing the fallow-season management practices at Akron, CO (table 7). These gains were largely attributable to increasing the amounts of surface residues, which enhanced water infiltration and suppressed evaporation. Use of improved varieties, weed control practices, and fertilizer practices also contributed.

Soil-water conservation reflects the combined effects of treatments on infiltration and evaporation, but these processes seldom are evaluated independently under field conditions. In Oklahoma, water content is often greater near the surface of residue-protected soil than in soil that has been clean tilled. The greater water content allows earlier establishment of wheat in this region where wheat provides forage for livestock in the fall, winter, and early spring grazing period (Krenzer et al. 1986).

At Lahoma, OK, water content was greater to a 4-ft depth where no-till rather than clean tillage was used (Heer and Krenzer 1989). In a monoculture winter wheat production system, the water content remained greater until the grain-filling period; however, grain yields were no greater with no-till than with clean tillage. Either water was not a yield-limiting factor during this study or other yield-limiting factors counteracted the benefits of the additional water.

No-till management can facilitate earlier planting of wheat in the fall. This earlier planting often results in more fall growth and forage production, which is beneficial in a cattle grazing-grain production system. However, lush fall and winter growth can use up so much soil water that little is left by grain-filling time and yields are depressed.

Long-term studies at Garden City and Tribune, KS, showed that mulch-tillage practices increased available soil-water content and dryland winter wheat and grain sorghum yields. Conventional, mulch-tillage, and no-till systems were compared in continuous wheat, wheat-fallow, wheat-sorghum-fallow, sorghum-fallow, and continuous sorghum cropping systems. The greater water content gained with mulch tillage and no-till increased wheat yields at both locations in the wheat-fallow system but only at Tribune in the wheat-sorghum-fallow system. Sorghum yields were more frequently increased by a reduction in tillage at Tribune, with the sorghum-fallow system yielding more than the wheat-sorghum-fallow system. Wheat yields in the wheat-fallow and wheat-sorghum-fallow systems usually did not differ at either location. The wheat-sorghum-fallow system was an effective cropping system at both locations in terms of water storage and crop yields. Its effectiveness improved when combined with the mulch-tillage and no-till systems, particularly at Tribune (Norwood et al. 1990).

At Bushland, TX, no-till, sweep, and disk methods were used during fallow after wheat in a study of an irrigated winter wheat-dryland grain sorghum-fallow rotation (two crops in 3 years). The no-till method produced superior results on average for four key parameters—precipitation storage as soil water, plant-available water at sorghum planting, sorghum grain yield, and water-use efficiency (table 8).

In another study at Bushland of an irrigated winter wheat-dryland grain sorghum-dryland sunflower rotation (three crops in 3 years), water storage during fallow after wheat and sorghum harvest was greatest with the no-till method (table 9). The tillage system used during fallow after wheat had no residual effects on sunflower yields or on yields of the next wheat crop.

In still another study at Bushland, this one involving irrigated winter wheat followed by irrigated grain sorghum on graded-furrow plots, no-till produced better water storage and sorghum yields than disk treatments (table 10).

Infiltration

Tillage system may or may not influence infiltration. At Woodward, OK, conventional and no-till watersheds had identical runoffs of 5.1 inches/yr, while range watersheds had only 0.4 inch/yr. Sediment loss, however, was much lower with no-till than with conventional tillage—1.3 versus 30.3 tons/acre/yr in 1985 and 1986 (Berg et al. 1988).

On a clay loam with a slope of less than 1.0 percent at Bushland, runoff for the period 1984–91 averaged 1.7 and 1.1 inches/yr from no-till and sweep-tillage watersheds, respectively, that were cropped in a dryland wheat-grain sorghum rotation. At planting time for both crops, soil-water content was greater with no-till because of less evaporation (fig. 3). Wheat yields were similar for both watersheds, but sorghum yielded more with no-till (Jones 1992). In all regions of the United States, but particularly in the semiarid regions, appreciable amounts of water are lost to evaporation when tillage exposes water in moist soil to the dry atmosphere. This water must be replaced before water can be stored at a greater depth. By using no-till, farmers avoid these tillage-accelerated evaporative losses.

Evaporation

Soil-water evaporation generally decreases as surface residue increases. In fields in Colorado worked with no-till, minimum tillage (herbicides plus sweep), and conventional tillage (sweep), the water content to a 6-inch depth averaged 27 percent the first day after 0.53 inch of rain. After 34 days with no additional rain, water content was low (5 percent average) in the surface 1 inch of soil in all fields but showed a greater increase with depth in the minimum- and no-till fields than in the conventional-till field. Average water content to the 6-inch depth was 6 percent, 11 percent, and 15 percent, respectively, in the conventional-, minimum-, and no-till fields. Surface residue amounts were 0.5, 1.2, and 1.5 tons/acre in the respective fields.

When runoff is prevented, as on level-bordered plots, soil-water storage reflects the influence of treatments on soil-water evaporation. In such plots at Bushland, precipitation storage as soil water during fallow averaged 35 percent with no-till and 21 percent with disk tillage in an irrigated winter wheat-irrigated grain sorghum study. Average grain sorghum yields were 4,550 and 3,640 lb/acre with no-till and disk tillage, respectively, using 6 inches of growing-season irrigation; they were 5,760 and 5,330 lb/acre, respectively, with 12 inches of irrigation (Musick et al. 1977).

References

Berg, W.A., S.J. Smith, and G.A. Coleman. 1988. Management effects on runoff, soil, and nutrient losses from highly erodible soils in the southern plains. *Journal of Soil and Water Conservation* 43:407–410.

Greb, B.W. 1979. Reducing drought effects on croplands in the west-central Great Plains. U.S. Department of Agriculture Information Bulletin No. 420.

Greb, B.W., D.E. Smika, and A.L. Black. 1967. Effect of straw-mulch rates on soil water storage during summer fallow in the Great Plains. *Soil Science Society of America, Proceedings* 31:556–559.

Heer, W.F., and E.G. Krenzer, Jr. 1989. Soil water availability for spring growth of winter wheat (*Triticum aestivum* L.) as influenced by early growth and tillage. *Soil and Tillage Research* 14:185–196.

Jones, O.R., V.L. Hauser, and T.W. Pophau. 1994. No-tillage effects on infiltration, runoff and water conservation on dryland. *Transactions of the American Society of Agricultural Engineers* 37:473–479.

Krenzer, E.G., Jr., R.L. Burton, F.J. Gough, et al. 1986. Oklahoma tillage update report. In *Proceedings of the Southern Region No-Tillage Conference*, June 1986, pp. 89–94. Southern Region Series Bulletin 319. University of Kentucky, Lexington.

Musick, J.T., A.F. Wiese, and R.R. Allen. 1977. Management of bed-furrow irrigated soil with limited- and no-tillage systems. *Transactions of the American Society of Agricultural Engineers* 20:666–672.

Norwood, C.A., A.J. Schegel, D.W. Morishita, and R.E. Gwin. 1990. Cropping system and tillage effects on available soil water and yield of grain sorghum and winter wheat. *Journal of Production Agriculture* 3:356–362.

Unger, P.W. 1978. Straw-mulch effect on soil water storage and sorghum yield. *Soil Science Society of America, Journal* 42:486–491.

Unger, P.W. 1984. Tillage and residue effects on wheat, sorghum, and sunflower grown in rotation. *Soil Science Society of America, Journal* 48:885–891.

Unger, P.W., and A.F. Wiese. 1979. Managing irrigated winter wheat residues for water storage and subsequent dryland grain sorghum production. *Soil Science Society of America, Journal* 43:582–588.

Additional Sources

Gerik, T.J., and B. L. Harris, eds. 1987. Conservation tillage: today and tomorrow. *Proceedings of the Southern Region No-Tillage Conference*, College Station, TX, July 1987. Texas Agricultural Experiment Station Miscellaneous Publication MP-1636, College Station.

Singh, R.P., J.F. Parr, and B.A. Stewart, eds. 1990. Dryland agriculture—strategies for sustainability, advances in soil science, vol. 13. Springer-Verlag, New York.

Unger, P.W. 1984. Tillage systems for soil and water conservation. 1984. *FAO Soil Bulletin* 54. Food and Agriculture Organization of the United Nations, Rome.

Table 5. Straw-mulch effects on the combined average efficiency of soil-water storage at Sidney, MT, Akron, CO, and North Platte, NE, 1962-65

Mulch rate (tons/acre)	Precipitation during fallow period (inches)	Water-storage efficiency (%)
0.0	14	16
0.8	14-22	19-26
1.5	14-26	22-30
3.0	14-26	28-33
4.5	26	34

Source: Greb et al. 1967

Table 6. Straw-mulch effects on soil-water storage during fallow*, on water-storage efficiency, and on dryland grain sorghum yield at Bushland, TX, 1973-76

Mulch rate (tons/acre)	Water storage (inches)	Water storage efficiency† (%)	Grain yield (lb/acre)
0.0	2.8 c‡	23 c‡	1590 c‡
0.5	3.9 b	31 b	2150 b
0.9	3.9 b	31 b	2320 b
1.8	4.6 b	37 b	2660 b
3.6	5.5 a	44 a	3280 a
5.4	5.8 a	46 a	3560 a

Source: Unger 1978

* Fallow period of 10-11 months

† Water storage determined to 6-ft depth. Precipitation averaged 12.5 inches.

‡ Column values followed by the same letter are not significantly different at the 5 percent level, using Duncan's Multiple Range Test.

Table 7. Effects of tillage systems during fallow on water storage and wheat yields, Akron, CO

Years	Type of tillage during fallow*	Water storage		Wheat yield (lb/acre)
		(inches)	(% of precipitation)	
1916-1930	Maximum tillage: plow, harrow (dust mulch)	4.0	19	960
1931-1945	Conventional tillage: shallow disk, rod weeder	4.6	24	1040
1946-1960	Improved conventional tillage; began stubble mulch in 1957	5.4	27	1540
1961-1975	Stubble mulch; began minimum tillage with herbicides in 1969	6.2	33	1930
1976-1990	Projected estimate; minimum tillage; began no-till in 1983	7.2	40	2400

Source: Adapted from Greb 1979

* Based on a 14-mo fallow period, from mid-July to second mid-September

Table 8. Effect of tillage method on four parameters in a winter wheat-grain sorghum-fallow rotation at Bushland, TX

Method	Precipitation stored as soil water (%)	Plant-available water to a 6-ft depth at sorghum planting (inches)	Sorghum grain yield (lb/acre)	Water-use efficiency (lb/acre-inch)
No-till	35	8.5	2800	202
Sweep	23	6.7	2230	175
Disk	15	6.0	1720	150

Source: Unger and Wiese 1979

Table 9. Effect of tillage method on average soil-water storage during fallow* after irrigated winter wheat and on subsequent dryland grain sorghum yields at Bushland, TX, 1978-83

Method	Water storage† (%)	Grain yield (lb/acre)
Moldboard	29 b‡	2290 bc‡
Disk	34 ab	2120 cd
Rotary	27 b	1960 d
Sweep	36 ab	2470 b
No-till	45 a	2980 a

Source: Unger 1984

* Fallow period of 10-11 months

† Fallow-period precipitation averaged 12.4 inches

‡ Column values followed by the same letter or letters are not significantly different at the 5 percent level, using Duncan's Multiple Range Test

Table 10. Effect of tillage method on irrigated winter wheat followed by irrigated grain sorghum in graded-furrow plots at Bushland, TX

Method	Precipitation stored as soil water during fallow (%)	Infiltration depth of irrigation water in growing season (inches)	Sorghum grain yield (lb/acre)
No-till	47	6.7	4830
Disk	28	3.5	3800

Source: Musick et al. 1977

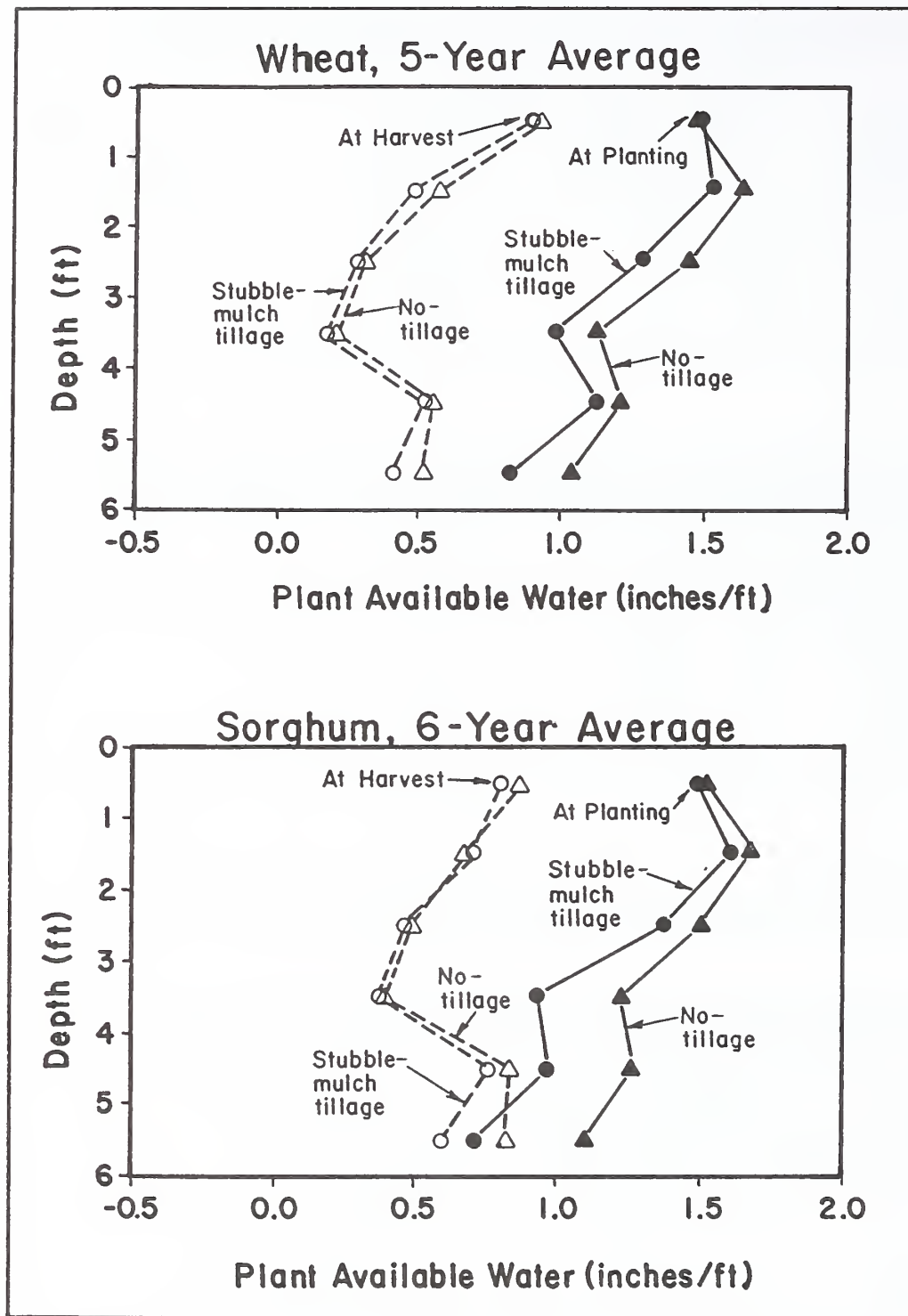


Figure 3. Effects of tillage system on soil-water content at planting and harvest of dryland winter wheat and grain sorghum, Bushland, TX, 1987-91. (Adapted from Jones et al 1994.)

Z Measuring Surface Residue and Calculating Losses from Decomposition and Redistribution

Jean L. Steiner, Harry H. Schomberg, and J.E. Morrison, Jr.

How Much Residue Is Necessary?

Surface residue decreases over time through natural decomposition, redistribution by tillage, and losses from wind and water. Management practices must therefore protect the soil adequately during critical erosion periods. In areas where erosion is primarily by water, the required amount of residue is based on the percentage of soil cover (for example, 30 percent residue cover remaining after planting the subsequent crop). Where erosion is primarily by wind, the residue requirement is often based on small-grain equivalent, which must be estimated from the mass and distribution (standing or flat) of the harvested crop. In either case, the farmer needs to determine the mass or cover of residue following harvest in order to evaluate the appropriateness of planned management operations.

Estimating Initial Residue Mass

Initial residue mass can be estimated from yield (table 11). These values can vary depending on management practice, growing season, and crop variety. Because of this variability, it is preferable to measure the actual amount of residue mass or cover.

Harvesting techniques also influence the height and distribution of surface residues left behind. Where wind erosion is important, standing stems are most effective at protecting the soil because they act as small windbreaks, slowing the wind speed at the soil surface and decreasing the wind energy available to detach soil particles. Stems should be left as tall as possible for maximum protection, while still allowing planter clearance for the next crop.

Measuring Residues

Mass. Residues should be collected from three or more areas of about 10 ft² that are representative of the field, and the areas should be sampled from midrow to midrow. To collect residue from a 10-ft² area, cut the plant residue from 12 linear ft of 10-inch rows, 10 linear ft of 12-inch rows, 4 linear ft of 30-inch rows, 3.33 linear ft of 36-inch rows, 3 linear ft of 40-inch rows, and so on. It is preferable to collect standing stems separately from surface residues and then to count the stems. Store the residues in a warm, dry environment for 2–4 days before weighing to allow them to

air dry. Relatively clean samples can be collected immediately following harvest. But after aging, a large and highly variable amount of soil will be collected with the residues, which causes overestimation of residue mass.

Percentage of cover. The line-transect method provides a good estimate of soil cover for flat, randomly distributed residues. However, the method is difficult to apply and interpret when a large percentage of the residue is standing. To make a line-transect measurement, stretch a tape or string with 50 or 100 markings across the field at a 45° angle to the rows. Walk along the line, look straight down, and count the number of times a piece of residue is under the mark. It is important to use small marks and to always view the same portion of the mark for accuracy. Using a tape with 100 points, the number of “hits” indicates the percentage of cover; for a tape with 50 points, multiply the number of hits by 2. Average the results from at least three transect counts for a field.

An alternative is to compare the appearance of the field with that in standardized photographs available from the Soil Conservation Service (SCS) or county extension offices. To use these photographs, stand in the field and look directly down. The more similar the field is to the photographs in residue age and tillage history, the easier it is to estimate cover. As the conditions of the field diverge from those in the photographs, the results achieved become highly user dependent. Estimates made looking across a field, such as from a vehicle, generally overestimate residue cover.

Small-grain equivalent. The small-grain equivalent represents a standard selected during development of the wind erosion equation by the USDA Agricultural Research Service, Manhattan, KS. The small-grain equivalent relates the protection offered by a specific crop residue to the protection provided by 10-inch lengths of small-grain straw oriented parallel to the prevailing wind in 10-inch spaced rows. Generally, a small-grain equivalent of 1,000 lb/acre after planting the subsequent crop is required to provide adequate protection. SCS has charts to convert the mass of various residues or seedling crops in different orientations to the small-grain equivalent.

Figure 4 shows how grain sorghum and wheat residues are converted to small-grain equivalents. Note that it only takes about 250 lb/acre of 10-inch standing wheat stubble or 550 lb/acre of randomly distributed 10-inch-long wheat residue to provide small-grain-equivalent protection of 1,000 lb/acre. This is due to the orientation of the residue, which determines its effectiveness in controlling wind erosion.

Relationship of Residue Mass to Residue Cover

The relationship of residue mass to cover is shown for six crops in figure 5. The relationship is very flat at high residue levels, so considerable decomposition of mass may occur

before losing a large amount of cover. If the residue level following harvest is low (about 1.5 tons/acre), loss of mass will be associated with considerable loss of cover. Residues that have a high proportion of leaf material following harvest may lose considerable cover with little loss in mass in that leaf material decomposes rapidly and is lighter than stem material. Soluble carbohydrates, which compose as much as 20 percent of the mass at harvest, can leach out with little change in cover. Decomposition may occur in the stem's interior, leaving the stem exterior—and cover—relatively intact.

Standing and Flat Residues

As mentioned previously, standing stems reduce the wind speed near the soil surface; this reduction is a function of standing stem silhouette area [stem diameter (inches) $\times$ stem height (inches) $\times$ stem no./1,600 inch²] (see fig. 7, p. 32). Flat residue cover increases surface roughness, acts as nonerodible material, and offers shelter to stop moving soil particles.

Standing residues contribute less cover than flat residues to protect the surface from the impact of raindrops, but standing stems persist longer because they decompose more slowly. Standing stems probably provide more protection than that estimated from a vertical view (either that estimated from the line-transect method or from SCS photographs) because most erosive rains come in storms where strong winds blow rain at an angle to the surface. The stems intercept blown rain along the length of the stem, reducing the direct impact of raindrops on soil particles.

Decomposition Rate

Factors that influence decomposition rate include the type of crop residue, moisture availability, and temperature. Leaf material decomposes much faster than stems or leaf sheaths. Crops that produce a large proportion of stem material, therefore, provide greater soil protection through the season. Residues decompose fastest under warm temperatures and moist conditions, which enhance microbial activity. Decomposition is slower in dry or cold environments. Buried residues decompose faster than standing and surface residues because of moist conditions below the soil surface.

Expected mass loss from residues and decrease in stem number can be estimated in various climates using daily temperature and precipitation information. These estimates are based on controlled experiments where maximum decomposition is measured under warm, moist conditions. The number of standing stems decreases after stem bases decompose; then the weakened stems fall over in response to a physical force such as strong wind or precipitation.

Decomposition patterns change considerably in different climatic regions. After typical local harvest, the approximate time to reduce standing winter wheat stems by 50 percent would be 60 days at Concordia, KS, 110 days at Temple, TX, 220 days at Bushland, TX, and 300 days at Akron, CO (fig. 6). Temperatures are warm at harvest at all locations. Precipitation is greater at Concordia during the first few months after harvest than at the other sites, so decomposition proceeds rapidly. Decomposition begins slowly at Temple because relatively little rain is received in the summer. During the winter at Temple, decomposition continues because of mild temperatures and moderate precipitation. In winter at Bushland, stem number decreases slowly, because winter temperatures are frequently above freezing; decreasing numbers are associated with each precipitation event. Little stem loss occurs during the relatively dry period following harvest at Akron because the stem bases do not completely decompose before winter. In winter at Akron and Concordia, almost no decomposition occurs because of cold temperatures.

Residue Redistribution

The Equipment Manufacturers Institute, Chicago, and SCS recently reviewed available data to summarize the range of residues remaining following specific tillage operations (table 12). Some types of residues are more fragile than others, and so certain tillage operations bury them more completely. Two general modifying factors should be considered when using the numbers in table 12, namely, that less residue is buried with (1) shallower operating depth and (2) slower operating speed. As residues age, they become more fragile and a lower percentage may remain following a specific operation than that left by tillage shortly after harvest.

Because the values in table 12 depend on the design of the specific implement, travel speed, soil type, soil-moisture content, and residue distribution, the percentage of cover should be measured before and after tillage to determine burial coefficients for actual operations. Before tilling a whole field, a test strip should be tilled to evaluate residue burial and to make needed adjustments. An example that uses table 12 to estimate residue cover at planting follows:

Assume 90 percent cover (C) following wheat harvest (a nonfragile crop) and 0.8 of this remaining after decomposition (D) losses during a long fallow period. For weed control, use 2 operations with a chisel plow with sweeps (SW, 0.7 remaining) and 2 undercutting operations with a 30-inch-wide v-blade sweep (VB, 0.9 remaining). For sorghum planting use a conventional planter with runner openers (P, 0.9 remaining). The residue cover after planting would be

$$\begin{aligned} & C \quad D \quad SW \quad SW \quad VB \quad VB \quad P \\ (90\%) & \times (0.8) \times (0.7) \times (0.7) \times (0.9) \times (0.9) \times (0.9) \\ & = 26\%. \end{aligned}$$

This value may be lower than the residue cover specified in the conservation plan. You may be able to leave the needed additional residue by modifying speed or depth of tillage or both. For instance, by reducing operating speed and depth of sweep operations, one could assume that 80 percent cover remained following the chisel plow with sweep operations and 95 percent remained following the undercutting operations. The cover after planting would be

$$\begin{array}{ccccccc} C & D & SW & SW & VB & VB & P \\ (90\%) \times (0.8) \times (0.8) \times (0.8) \times (0.95) \times (0.95) \times (0.9) \\ = 37\%. \end{array}$$

Such relatively minor changes in management operations would provide considerably more protection from erosion by leaving 37 percent cover, as opposed to the 26 percent cover left in the first scenario. In general, if time permits, slower tillage is a good investment toward erosion control. Alternatively, herbicide application could be substituted for some of the weed-control operations in years when a smaller amount of residue than usual was produced. Although the sprayer knocks down a few stems, the impact of a spray rig on residue cover is negligible.

Principles of Residue Management

1. Residues should be measured before and after tillage operations to gain an understanding of residue burial under local conditions.
2. Attached residues, as opposed to not shredded or undercut residues, are retained on the surface better during high winds and planting or drilling operations.
3. Twisted chisel points are designed to cover residues with soil and should not be used in most of the southern Great Plains, where excessive residues are seldom a problem.
4. Disk harrows (tandem, offset, and so on) should not be used behind peanut, soybean, or cotton crops because they bury the fragile leaf material and leave the soil without adequate protection. Neither should they be used on wheat unless necessary for reduction.
5. Soil lifting-throwing tillage equipment (shallow chisel, field cultivator, disks) buries more residue with increased field speed and increased tillage depth.
6. Undercutting types of tillage equipment with horizontal blades bury the same amount of residue regardless of speed.
7. Rolling coulters, which are placed ahead of each undercutting tillage shank, cut residue and soil, allow more uniform flow around the shank, and cause less residue burial.
8. Gangs of straight coulters bury less residue than gangs of disk blades on the front of combination-tillage implements with chisel shanks.
9. Undercutting sweeps preceded by coulters can be used for row-crop cultivation to reduce residue burial; disk hillers on ridge-tillage cultivators rebuild ridges or beds but bury residues.

10. Rolling finger-type "trash rakes" move residues out of the path of planter/drill-furrow openers and when properly adjusted do not bury residues.
11. Some chemical weed control may need to replace tillage used for weed control when the crop produces less than the planned amount of residue and maximum retention of residue is desired.

Table 11. Estimates of initial crop residue from harvested yield

Yield (lb/acre)*	Crop Residue Remaining in the Field (lb/acre)					
	Corn	Sorghum	Small grains	Sunflowers	Cotton	
					Picked	Stripped
0		1000	350	0	0	0
100		1100	500	250	600	500
250		1300	700	650	1500	1200
500		1550	1100	1300	3050	2400
1000	3800	2150	1900	2600	6050	4750
1500	4050	2700	2650	3900	9100	7150
2000	4300	3250	3450	5200		
3000	4850	4400	5000	7750		
4000	5350	5550	6550			
5000	5850	6650	8100			
7000	6850	8900	11250			
9000	7900	11200				
10,000	8400					
12,000	9400					

* At harvest the moisture content of grain or seed is about 9 percent for sunflowers, 12 percent for wheat, and 13 percent for corn and grain sorghum. If yield is not corrected for moisture content, dry-crop residue will be slightly overestimated.

Table 12. Percentage of residue remaining following different tillage operations

Implement	Nonfragile*	Fragile†
	% Remaining	
Plows		
Moldboard plow	0–10	0–5
Disk plow	10–20	5–15
Machines That Fracture Soil		
Paratill/paraplow	80–90	75–85
V-ripper/subsoiler		
12–14 inches deep, 20-inch spacing	70–90	60–80
Subsoiler plus chisel	50–70	40–50
Disk plus subsoiler	30–50	10–20
Chisel Plows		
With sweeps	70–85	50–60
With straight-chisel spike points	60–80	40–60
With twisted points or shovels	50–70	30–40
Combination Chisel Plows		
Coulter chisel plows		
With sweeps	60–80	40–50
With straight-chisel spike points	50–70	30–40
With twisted points or shovels	40–60	20–30
Disk chisel plows		
With sweeps	60–70	30–50
With straight-chisel spike points	50–60	30–40
With twisted points or shovels	30–50	20–30
Undercutters		
Sweep v-blade more than 30 inches wide	85–95	70–80
Sweeps 20–30 inches wide	80–90	65–75
Disk Harrows		
Offset or tandem		
Heavy plowing, more than 10-inch spacing	25–50	10–25
Primary cutting, more than 9-inch spacing	30–60	20–40
Finishing, 7- to 9-inch spacing	40–70	25–40
Light tandem disk after harvest	70–80	40–50
One-way disk		
With 12- to 16-inch blades	40–50	20–40
With 18- to 30-inch blades	20–40	10–30
Single gang disk	50–70	40–60
Field Cultivator Plus Leveling Attachments		
As the primary tillage operation		
Sweeps, 12–20 inches	60–80	55–75
Sweeps or shovels, 6–12 inches	55–75	50–70
Duckfoot points	35–60	30–55
As a secondary operation		
Sweeps, 12–20 inches	80–90	60–75
Sweeps or shovels, 6–12 inches	70–80	50–60
Duckfoot points	60–70	35–50

Implement	Nonfragile*	Fragile†
	% Remaining	
Finishing Tools		
Combination finishing tools		
With disks, shanks, and leveling attachments	50–70	30–50
With springteeth and rolling basket	70–90	50–70
Harrows		
Springtooth (coil tine)	60–80	50–70
Spiketooth	70–90	60–80
Flextine tooth	75–90	70–85
Roller harrow (cultipacker)	60–80	50–70
Packer roller	90–95	90–95
Rotary tiller		
Secondary operation 3 inches deep	40–60	20–40
Primary operation 6 inches deep	15–35	5–15
Rod Weeders		
Plain rotary rod	80–90	50–60
With semichisels or shovels	70–80	60–70
Strip-Tillage Machines		
Rotary tiller, 12-inch, tilled on 40-inch rows	60–75	50–60
Row Cultivators, More Than 30-Inch Spacing		
Single sweep per row	75–90	55–70
Multiple sweeps per row	75–85	55–65
Finger-wheel cultivator	65–75	50–60
Rolling-disk cultivator	45–55	40–50
Ridge-till cultivator	20–40	5–25
Unclassified Machines		
Anhydrous applicator	75–85	45–70
Anhydrous applicator plus closing disks	60–75	30–50
Subsurface manure applicator	60–80	40–60
Rotary hoe	85–90	80–90
Bedders, listers, and hipers	15–30	5–20
Furrow diker	85–95	75–85
Mulch treader	70–85	60–75
Drills		
Hoe opener drills	50–80	40–60
Semideep furrow drill or press drill, 7- to 12-inch spacing	70–90	50–80
Deep-furrow drill with more than 12-inch spacing	60–80	50–80
Single-disk opener drills	85–100	75–85
Double-disk opener drills	80–100	60–80
No-till drills and drills plus attachments		
In standing stubble		
Smooth no-till coulters	85–95	70–85
Ripple or bubble coulters	80–85	65–85
Fluted coulters	75–80	60–80
In flat residues		
Smooth no-till coulters	65–85	50–70
Ripple or bubble coulters	60–75	45–65
Fluted coulters	55–70	40–60

Implement	Nonfragile*	Fragile†
	% Remaining	
Row Planters		
Conventional planters with		
Runner openers	85–95	80–90
Staggered double-disk openers	90–95	85–95
Double-disk openers	85–95	75–85
No-till planters with		
Smooth coulters	85–95	75–90
Ripple coulters	75–90	70–85
Fluted coulters	65–85	55–80
Strip-till planters (8- to 14-inch strip) with		
2 or 3 fluted coulters	60–80	50–75
Row-cleaning devices	60–80	50–60
Ridge-till planter	40–60	20–40
Decomposition‡		
Warm humid	65–85	60–80
Warm dry	70–90	65–85
Cool humid	70–90	65–85
Cool dry	75–95	75–90

* Nonfragile crops include alfalfa or legume hay, barley, buckwheat, corn, cotton, forage silage, grass hay, millet, oats, pasture, rice, rye, sorghum, triticale, and wheat. If a straw chopper or shredder is used to cut straw or other residue materials into small pieces, then the residues should be considered fragile.

† Fragile crops include canola, dry beans, dry peas, fall-seeded cover crops, grapes, green peas, guar, lentils, peanuts, potatoes, safflowers, soybeans, sugar beets, sunflowers, and vegetables.

‡ Loss of cover due to decomposition is highly variable during fallow periods and depends on length of the fallow, climate, crop material, and initial amount of residue.

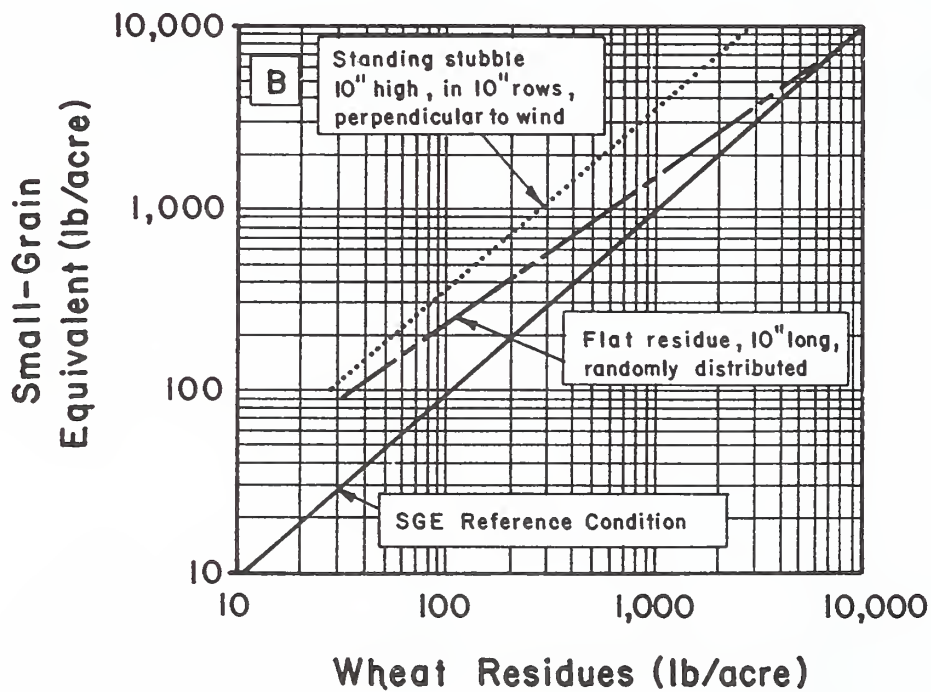
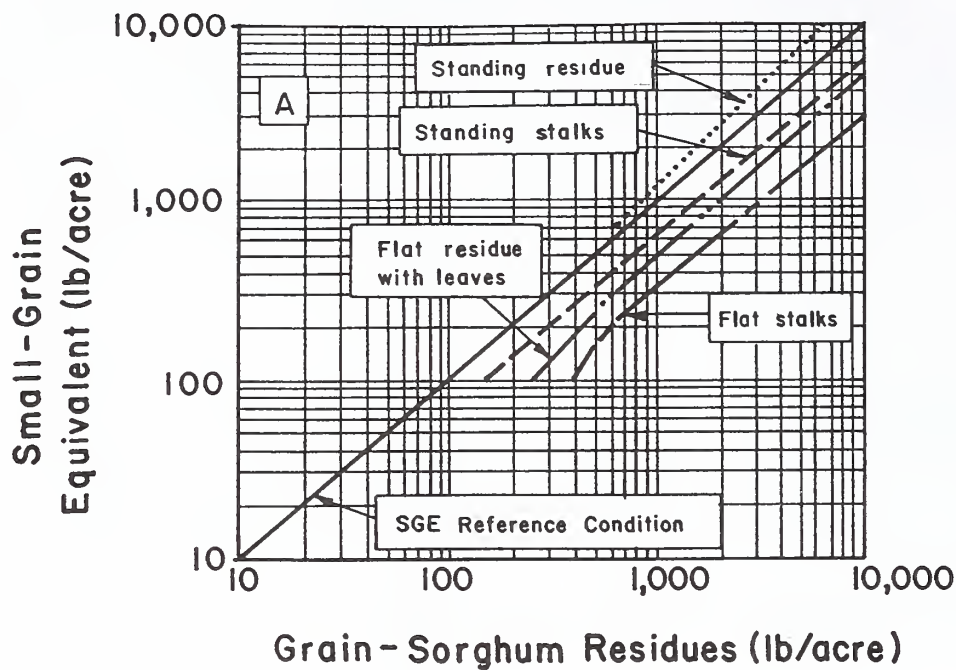


Figure 4. Relationship of grain-sorghum residues and wheat residues to small-grain equivalent (SGE)

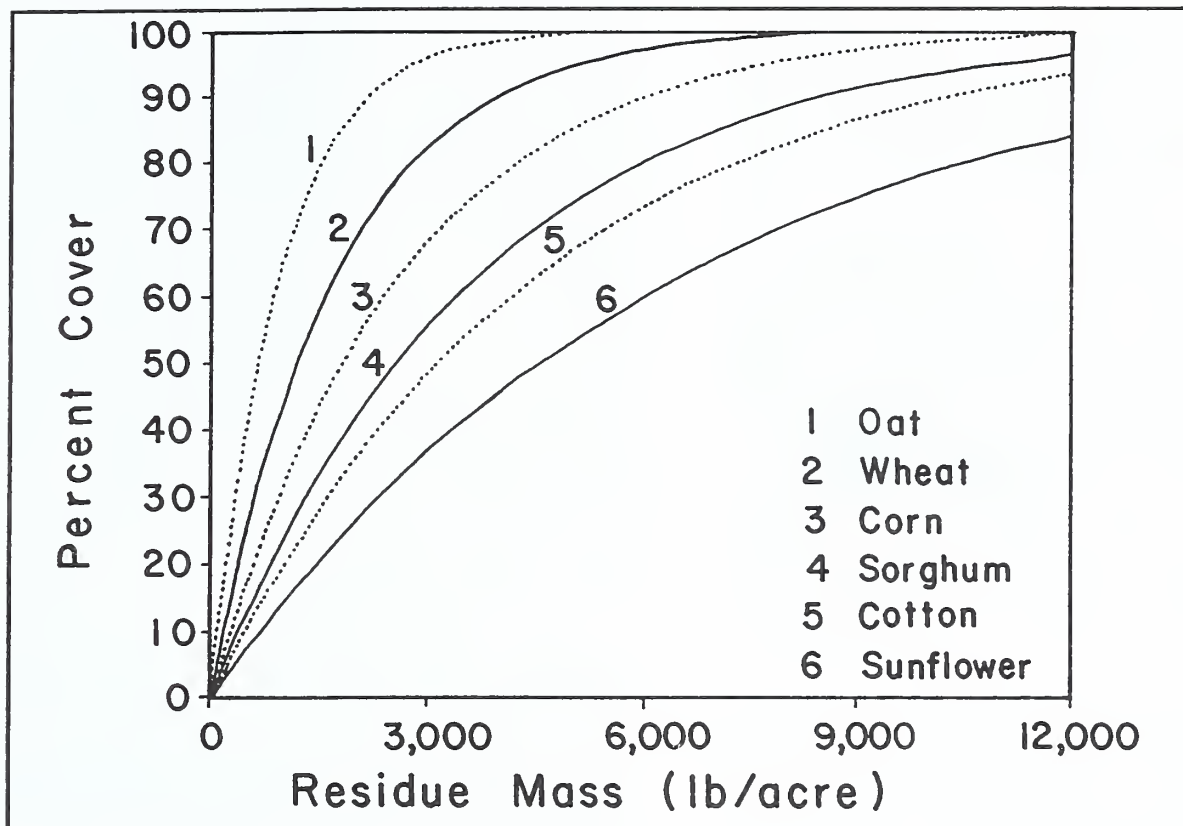


Figure 5. Relationship of residue mass to coverage

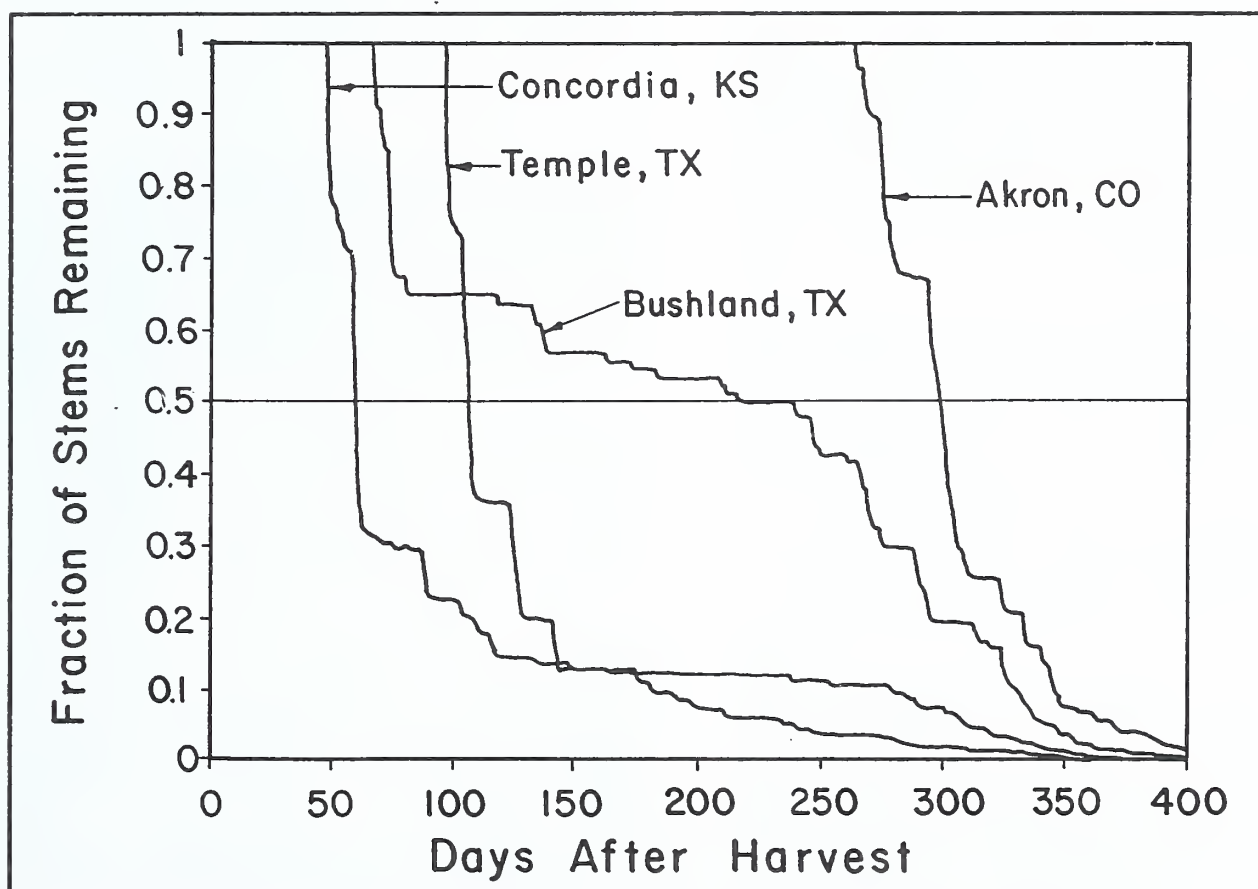


Figure 6. Decrease in standing-stem number over time as predicted from climatic conditions at four locations

8 Erosion Control with Sparse Residue

J.D. Bilbro, B.L. Harris, and O.R. Jones

Soil Loss and Residue Type

Within limits, the more residue on the soil surface the greater the reduction will be of wind and water erosion. But, even small amounts of residue, such as that produced by some dryland crops, can be of significant benefit in controlling wind and water erosion. Figure 7 shows the relationship between the percentage of soil cover provided by flat, randomly distributed residue and the soil-loss ratio. The soil-loss ratio equals the ratio of soil erosion with crop residue cover to soil erosion without crop residue under the same conditions. For example, if the soil has a 25 percent cover, the potential soil loss from wind erosion will be 37 percent of that on a bare field under the same conditions. Note that the effects of flat residue on water erosion are very similar to those on wind erosion.

Standing residue is much more effective than flat residue for controlling wind erosion. Figure 8 shows the relationship of silhouette area [stem diameter (inch) $\times$ height (inch) $\times$ number of standing stems per 1,600 inch² of soil area] and soil-loss ratio when the wind velocity is 35 mi/hr at 2 ft above the ground. For 10 sorghum stalks with a total silhouette area of 87.5 inches² per 1,600 inches² of soil, the soil-loss ratio would be 0.19. If these stalks were cut off at ground level and distributed over the surface evenly, ground cover would be 11 percent and soil-loss ratio would be 0.71. The soil-loss potential from wind erosion would be .71/.19=3.7 times greater if the stalks were flat on the surface than if they were standing.

Residue Quantities

High-residue crops include small grains, corn, some millets, forage sorghum, and grain sorghum. Low-residue crops include cotton, sunflowers, beans, peas, sesame, peanuts, soybeans, and most row crops harvested for silage. Residue production for a given crop can vary widely because the amount is primarily determined by growing conditions. However, seldom do low-residue crops produce enough residue to adequately control wind or water erosion on highly erodible lands, particularly in semiarid or drier regions.

If the residue is horizontal, protection afforded against wind and water erosion is primarily a function of soil cover, not pounds of residue. For example, achieving 50 percent ground cover on an acre with horizontal residue takes about 900 pounds of wheat straw, 2,700 pounds of grain-sorghum residue, and 8,100 pounds of cotton stalks. (For a related discussion of residue decomposition and the effects of tillage on residue redistribution, see chapter 7.)

Increasing Residue Production

Residue production can be influenced by crop selection, crop rotation, cover crops, and crop yield. Economics usually dictates the crop to be grown, but residue production can be increased by adopting production practices that conserve water and increase yield. For example, combining water conservation practices such as improved residue management, terracing, and furrow diking with good agronomic practices such as cultivar selection, disease and insect control, and adequate fertilizer will increase crop yields and residue production. Maintaining most or all residue on the surface conserves more water, further increases yields of subsequent crops, and creates a snowball-type effect on residue production. Good residue management thus results in more residue to manage, and wind and water erosion losses are minimized as a consequence.

Need for Complementary Practices

No-till or minimum tillage should be used whenever practical. Such systems sometimes provide adequate wind and water erosion control, especially if the crop is winter wheat or a similar crop. However, in areas that receive less than 20 inches of rainfall annually, residues remaining after harvest of most dryland row crops are sparse most years, and complementary practices must be used if erosion losses are to be brought down to a tolerable level. Some methods for achieving this level are given next. Often a combination of two or more of these practices is needed.

To Control Wind Erosion

Tillage. Tillage can control wind erosion if there is a reasonable amount of clay in the tillage zone and there is enough soil water for clods and ridges to form. The ranking of implements from most to least effective for forming a surface resistant to wind erosion is moldboard plow, bedder, chisel plow, and disk-type plow. Unfortunately, the moldboard plow is not only the most effective in producing a nonerodible surface, it is also the most effective in burying residue and oxidizing residual organic matter. So it should generally not be used except in cases where residue (even when coupled with other tillage operations) provides inadequate control. One should remember that tillage only controls erosion for as long as the surface remains in a roughened condition. Rainfall usually destroys the clods, and then another tillage operation is required.

Cover cropping, strip cropping. Cover crops are planted to protect the soil from wind erosion during a particular time of the year—generally during the season when the cash crop is not growing. Cover crops can be planted (preferably in rows spaced no more than 10 inches apart) after the cash crop is harvested, or they may sometimes be planted between rows of the cash crop before it is harvested (planting wheat into cotton, for example). This planting in between rows is a feasible

practice if irrigation is available or if rainfall is timely and adequate. Under dryland conditions, this practice is much less likely to succeed on coarser textured soils than on finer textured ones. The cover crop can be chemically killed when it has produced adequate ground cover (more than 60 percent), and the cash crop can then be seeded into the killed residue.

A special type of strip cropping can be used in areas producing dryland cotton. Many producers plant in a pattern of two planted rows and two skipped rows, in row widths of about 36–40 inches. Most years wind erosion can be adequately controlled by planting forage sorghum, rye, or similar crops in closely spaced rows (10 inches or less) within the blank rows in August or the first week of September. For maximum flexibility, the producer can plant the rye and forage sorghum in alternate blanks across the field. If the forage sorghum emerges by the end of August, chances are very good that it will produce enough growth by frost to adequately protect the soil (more than 60 percent coverage after it lodges) during the following highly erosive January–March period.

If the forage sorghum does produce sufficient growth, the producer has several options as to what to do with the rye: it can be destroyed immediately, allowed to grow until February and chemically killed for mulch, or allowed to grow for hay or seed. The producer should be aware that if the rye is allowed to grow to the haying or seed stage, the yields of the subsequent cotton crop could be reduced 10 percent or more, depending primarily on the amount of rainfall during the cotton-growing period.

In years when insufficient rain or an early freeze precludes adequate growth of the forage sorghum, the producer can allow the rye to grow to more than 60 percent ground cover; then it can be chemically killed to stop its soil-water use. Or if soil water appears to be adequate, the rye can be left for hay or grain. As was the case with cover crops sown between crop rows, this practice is much less likely to succeed on coarser textured soils than finer textured ones.

Wind barriers. Wind barriers should be oriented perpendicularly to the predominant direction of the erosive winds. Wind barriers may be either annual crops such as forage sorghum, grain sorghum, or millet, or they may be perennial grasses. The positioning of the wind barriers depends on the amount of protection their height affords and the erodibility of the soil. As a rule of thumb, for 1 ft of height the wind barrier protects 10 ft downwind from wind erosion. Unfortunately, most annual crops do not make a wind barrier more than 3–4 ft tall after the plants lodge following a freeze. Perennial grasses such as switchgrass, however, can make a barrier 5–6 ft tall that is retained throughout the year.

Other. Soil mulches can be made of materials such as cotton gin trash or the concentrated residue of various crops. Soil covered with more than 60 percent mulch seldom suffers any significant losses from wind erosion.

Soil binders are chemical formulations that form a film on the soil surface which resists wind erosion. They can be effective in special situations, such as instances where blowing sand would harm seedlings or where deposition of wind-blown sand would be damaging, but they are relatively expensive and may last only a short time.

To Control Water Erosion

The principles for controlling water erosion include minimizing the impact of raindrops on the soil, increasing the infiltration rate, and minimizing the distance that surface water can travel. If the soil is relatively level and fairly coarse in texture, water erosion usually can be adequately controlled with techniques such as improved residue management and simple tillage operations. However, the higher the silt and clay content and the more rolling the surface, the greater the likelihood that one or more of the following additional control measures will be needed.

Tillage and land forming. Tillage should be done with implements that allow infiltration of rainfall at a rate which precludes runoff. If the land is reasonably level, implements such as chisel plows are quite effective. If the land is rolling, then the following practices should be used either singly or in combination: chiseling, listing (bedding), furrow diking, terracing, or contouring.

Strip cropping. In some cases high-residue-producing crops like wheat can be planted in alternate strips with low-residue-producing crops such as sunflowers or soybeans. Residue from the small-grain crop provides an area that reduces runoff and that entraps soil eroded from the adjacent areas. With proper spacing and width of strips, this can be a very effective technique. Advice about proper spacing and width can be obtained from a local Soil Conservation District office.

Grassed waterways. Sometimes a field contains relatively small sites where runoff cannot be practically controlled by the aforementioned methods. Planting these areas in a permanent grass that is resistant to water erosion is often an effective alternative.

Grassed strips and hedges. Research shows that the first few feet of grass strips catch some of the sediment moving with concentrated flow but that most sediment settles in ponded water upstream from the strip. Continued deposition tends to fill the low area and diffuse the concentrated flow unless the ponded water pushes over the grass. Switch grasses, eastern gamma grass, and varieties of muscandus and vetiver grass have stiff stems and dense tillering habits that are not pushed over by a foot of ponded water. Hedges of these perennial grasses are used to reduce erosion and increase infiltration on hill slopes and to diffuse concentrated flows and fill ephemeral gullies.

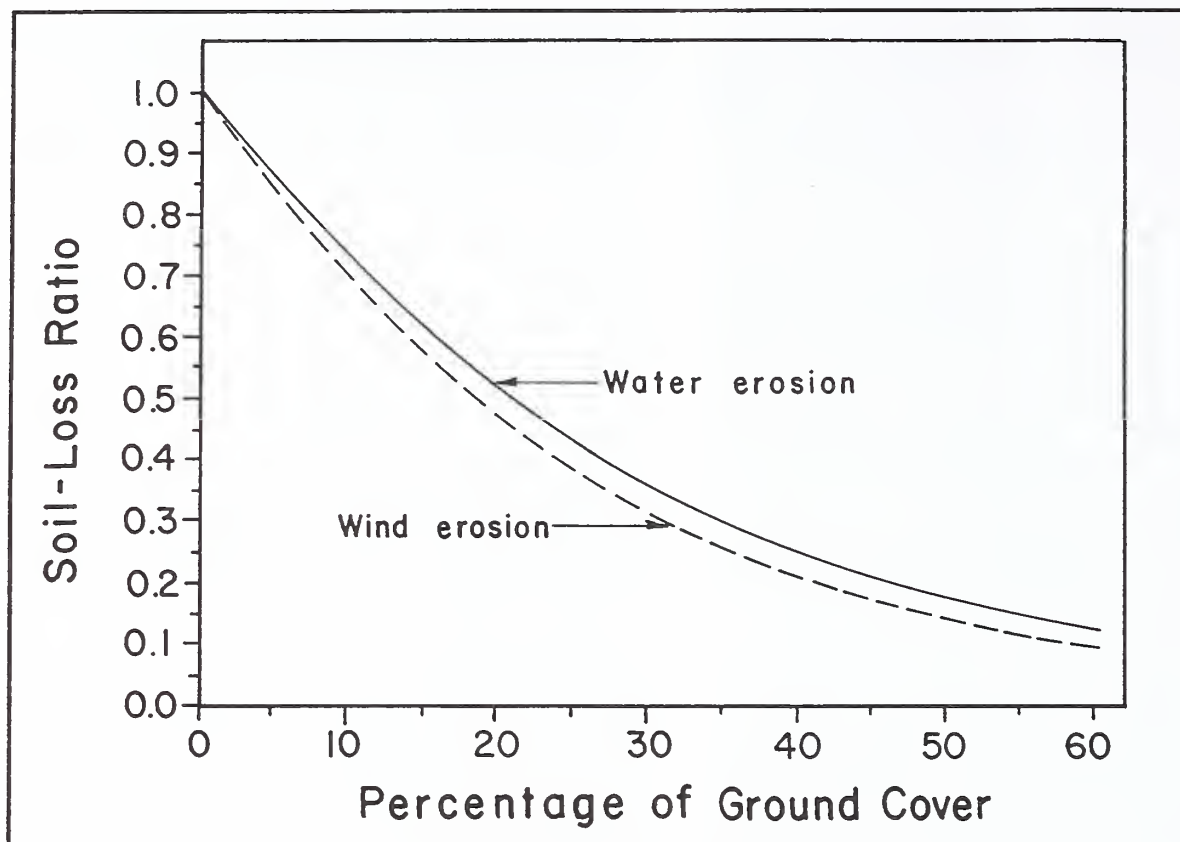


Figure 7. Relationship between percentage of ground cover of flat, randomly distributed residues and soil-loss ratio

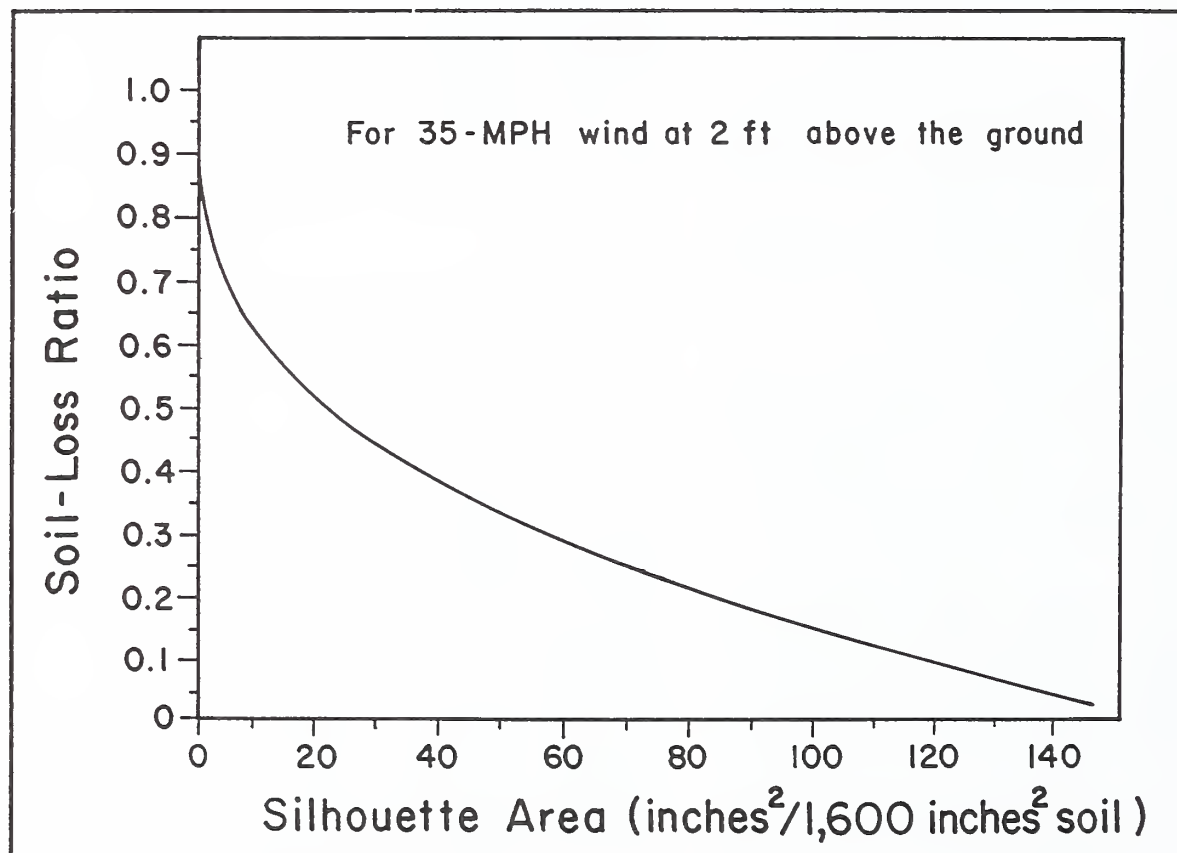


Figure 8. Standing crop residues: relationship of silhouette area and soil-loss ratio

9 Fertilizer Management

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Fertilizer management under conservation tillage has many similarities to that of conventional tillage systems. However, the presence of crop residue on the soil surface does present some challenges, particularly in fertilizer placement. Surface residue decomposes more slowly than buried residues, causing a decrease in the rate of nutrient release, particularly during the first few years after a shift to conservation tillage. Because of this effect, suboptimal nitrogen fertilizer rates with conservation tillage often cause greater reductions in yield than suboptimal rates with conventional tillage. Nutrient immobilization by microbes as they decompose residues will affect the fertilizer requirements of the crop. Volatilization losses of nitrogen from urea-containing fertilizers can be expected to be higher with conservation tillage than with conventional tillage due to the higher activity of urease in the crop residue. This chapter identifies ways to ensure the efficient utilization of applied plant nutrients in an environmentally safe manner under conservation tillage systems.

Soil Testing and Fertilizer Recommendations

One of the first steps in fertilizer management is to assess inherent and acquired soil fertility. This is done by using locally calibrated soil tests. The reliability and accuracy of a soil test is highly dependent on proper soil sampling, probably the most important step of the soil-testing procedure. Improper soil sampling can cause large errors in fertilizer recommendations.

Samples of surface soil samples (0–6 inches deep) should be collected from similar soils in a field for pH, lime requirement, soil organic matter, nitrate-nitrogen, phosphorus, potassium, and micronutrient analyses. A minimum of 15–20 individual soil cores should be composited for analyses. Samples of subsoil (6–24 or 48 inches deep) should also be collected to determine the residual nitrate, chlorine, and sulfate levels resulting from previous cropping and fertilizer history. Soil sampling should be done as close to planting time as possible. For routine soil analysis and fertilizer recommendations, samples should be collected to the tillage depth or 0–4 inches deep. The larger the proportion of the rooting depth sampled, the more accurate the nitrogen fertilizer recommendation will be. Reputable soil-testing laboratories should be used that consider the farmer's economic return of primary importance.

The environmental consequences of fertilizer application are also of primary importance in today's production systems. Reducing potential nitrate contamination of groundwater under irrigated and dryland soils, while maximizing

economic yields, depends chiefly on an accurate assessment of residual nitrate concentration in the soil profile. Profile nitrate concentrations after harvest can vary considerably due to (1) previous fertilizer programs, (2) crop yields and resulting nitrogen removal, (3) leaching by irrigation or rain water, (4) nitrogen losses by volatile losses of ammonia gas and by denitrification, and (5) immobilization.

Several models that recommend nitrogen levels are being used in the Great Plains. All conform to the following general equation:

$$\text{N fertilizer recommendation} = (\text{yield goal}) - (\text{soil test NO}_3) - (\text{Nmin}) - (\text{factors}) \quad [1]$$

where

N = nitrogen,

NO₃ = nitrate, and

Nmin = nitrogen mineralization.

In this model, *yield goal* more than any other factor influences the quantity of fertilizer nitrogen recommended. Thus, yield goals must be realistically projected to accurately determine optimum fertilizer rate. They should be based on average yield over the past 5 years plus no more than a 5 percent increase. Growers often overestimate their yield goals, resulting in excessive nitrogen fertilizer recommendations and the accumulation of large quantities of residual soil nitrate in the soil profile.

In the model, the *soil test NO₃* value is determined from soil sampling, preferably to the depth of the rooting zone but to a minimum of 2 ft. *Nmin*, the nitrogen mineralization term, includes adjustments for potential nitrogen mineralization from previous legume crops, for manure applications, and for nitrogen release from soil organic matter. In many instances, nitrogen release from organic matter is insignificant because little organic matter is left in the soil; this is particularly true in the southern Great Plains. Available mineral nitrogen may actually decrease with conservation tillage in that this practice may cause organic matter levels to increase. The *factors* term includes corrections for nitrogen in irrigation water, special cultural practices, or other soil and management factors that can affect nitrogen availability.

Many of the soils in the Great Plains are deficient in available potassium. Soil-testing procedures are available that result in accurate potassium fertilizer recommendations for all soils. Placement is more important with potassium fertilizers than with any other fertilizer material; it is discussed later in the chapter.

The most frequently deficient micronutrients in Great Plains soils are iron and zinc. These deficiencies normally occur on soils with a high pH that contain free lime and on eroded areas where calcareous subsoils are exposed. However, the

DTPA soil test (as described by Olsen and Ellis 1982) accurately identifies deficient soils, enabling sound fertilizer recommendations. Soil-zinc deficiencies can be corrected with applications of inorganic or organic zinc fertilizer materials. Iron deficiencies in iron-sensitive crops such as sorghum, beans, and corn present a unique problem. No economical fertilizer materials are available for correction of iron deficiencies in high-pH soils. Foliar application is the only viable method of correcting iron deficiencies in these soils, but it may not be cost-effective if more than one application is necessary. Rotation to crops that are not sensitive to low levels of soil iron is generally the most logical and economical alternative. Application of manure can correct iron deficiencies if used at high-enough rates. Caution should be exercised to ensure that salt damage does not occur with excessive manure applications.

Deficiencies of manganese, copper, chlorine, molybdenum, and boron are rare in the Great Plains. Responses to chloride have been observed, but these effects are usually not nutritional. They are generally the result of suppression of root rot and foliar diseases.

Fertilizer Placement

Maximum crop recovery of applied nutrients generally occurs when fertilizers are applied below the soil surface in the vicinity of actively growing roots. In high-residue dryland cropping systems, subsurface fertilizer placement offers three advantages over broadcast application: (1) placement in moist soil where roots are actively growing, (2) concentration of nutrients in bands, resulting in fewer soil interactions and thus greater nutrient availability, and (3) minimization of nutrients tied up by surface crop residue.

Conflicting reports can be found in the literature regarding the yield advantages of various nitrogen placements. If applied under the correct conditions, surface-applied nitrogen fertilizers can be as efficient as subsurface applications. Loss of nitrogen fertilizers from surface applications is covered in the next section.

Subsurface placement of phosphorus fertilizers is important because of their immobility and chemical reactivity with the soil, which can result in rapid phosphorus fixation. The advantages of certain placements are, however, dependent on soil properties, mainly their phosphorus-fixing capacity. Compared with broadcast applications, the rate advantages offered by band placement of phosphorus fertilizers can range widely. As indicated in figure 9, band applications near the row can have considerable advantage over broadcast applications on low-phosphorus soils and little or no advantage on medium- to high-phosphorus-testing soils. Since phosphorus fertilizers have low salt indexes, placement with small-grain seeds in narrow row spacing (up to 14 inches) is an excellent placement method. Decisions

regarding phosphorus fertilizer placement should be based on levels obtained from a soil test.

Volatilization of Nitrogen Fertilizers

Loss of nitrogen fertilizers as gaseous ammonia can occur when ammonium-containing fertilizers are surface applied to calcareous soils or when urea is surface applied to any soil. The magnitude of loss varies widely, ranging from 0 to 50 percent depending on the soil and climatic conditions. Gaseous ammonia loss from urea generally increases with increasing soil pH and surface crop residues. Crop residues promote ammonia volatilization by maintaining moist, humid conditions at the soil surface and increasing the hydrolysis of urea. Subsurface placement is the only solution to decrease nitrogen losses. In no-till systems, band applications are the alternative; in reduced tillage systems, the nitrogen fertilizer may be applied during one of the tillage operations, resulting in incorporation into the soil. In areas where there will be insufficient irrigation to cause nitrate leaching, nitrogen fertilizers can be applied long before planting. However, in areas where the probability of leaching is significant, careful consideration of leaching potential and subsequent possibility of groundwater contamination should govern this decision.

Managing Soil pH

No-till systems that result in minimal disturbance of the soil year after year may promote acidification of the top 2–3 inches of soil. This acidity arises mainly from nitrification of ammoniacal fertilizers that were surface applied, crop removal of basic elements like calcium and potassium, and production of organic acids from the microbial degradation of surface crop residue. Acidity is not a management problem in calcareous soils. But, in neutral to acid soils the surface pH may decrease to a point where problems with plant growth result. If surface pH falls below 5.0, aluminum toxicity may occur, especially on coarse-textured soils. Broadcast application of finely divided agricultural limestone corrects the problem.

The benefits from more frequent applications of smaller amounts of lime in no-till systems, where incorporation is not possible, should be carefully weighed against their cost. Soil tests for lime recommendations are available at most soil-testing laboratories. Long-term benefits can result from processes by which concentration of crop residues and ammoniacal fertilizers develop acids, which then dissolve the lime and mobilize the calcium so it moves out of the surface soil. As indicated in figure 16 (page 65), for example, in 18 years of no-till management in an Ohio watershed, one ton of lime applied per acre every other year and surface applications of ammoniacal nitrogen mobilized the calcium sufficiently to increase the pH of the acid subsoil to a depth of about 60 cm. This neutralization of acidity and associated calcium availability in subsoils is

believed to increase the rooting depth of crops, provide them with a larger reservoir of water, and contribute to observed increases in production.

Managing Manure

Manure use in conservation tillage produces benefits and carries limitations. If possible, manure should be incorporated into the soil before implementing conservation tillage. Agronomically sound rates should be used to ensure that buildup of soil nitrate does not occur. Application rate should be based on the nitrogen content of the manure, crop yield goal, and the same factors included in equation 1. If manure is applied to established conservation tillage systems where soil incorporation is not possible and if runoff is common during intense rainfall, special precautions such as retention basins, or grass strips or hedges for filtration should be considered to keep the manure and its constituents on the farm.

Manure has good nutritional value in conservation tillage systems. Volatilization of a large portion of ammonia- and urea-containing compounds will occur if the manure is left on the soil surface, especially on soils with high pH. The organic nitrogen fraction of the manure will decompose much like that of a crop residue, only at a more rapid rate due to its higher nitrogen content. A general guideline for availability of the portion of nitrogen in manure that is not volatilized is that 50 percent of it becomes available during the application year, 25 percent the second year and 12 percent the third year. Large variations from normal soil moisture and temperature affect the release rate. Surface-applied manure also contributes to the residue cover on the soil surface, resulting in reduced impact from raindrops, reduced soil erosion, and increased water capture and retention efficiency.

Strategies To Increase Fertilizer Efficiency

Several strategies can be integrated with surface crop residue management to increase nitrogen uptake efficiency. Nutrients must be applied below the residue layer for maximum uptake. Subsurface band applications of nitrogen, phosphorus, and other nutrients not only increase potential nutrient availability but also decrease immobilization of nutrients by soil organisms, reduce losses from ammonia volatilization, and decrease nutrient-soil fixation. In no-till systems, planting equipment can be modified to band apply fertilizers at planting. Solution fertilizers are well suited to band applications because the fertilizer pumps are relatively inexpensive and equipment modifications are not complex. Split applications of nitrogen generally increase the efficiency of nitrogen utilization. Timing the applications to coincide with plant nutrient needs optimizes nitrogen utilization.

Increasing the efficiency of nitrogen use under no-till requires appropriate planning and, as mentioned, may require equipment modifications. Under minimum tillage, the fertilizer can be applied prior to a tillage operation, so it is incorporated into the soil during tillage and thus achieves maximum utilization. The Soil Conservation Service has given credit (equivalent to erosion control for no-till) for use of strip-tillage and row-tillage systems where anhydrous fertilizer is applied with knives, leaving a tilled strip into which seed for the next crop is subsequently sown.

Preventing Nonpoint Pollution

By allowing accumulation of more residue on the soil surface, crop residue management lessens nonpoint pollution from fertilizers. The residue reduces surface runoff from intense or prolonged rainfall events, and this reduction decreases soil erosion and associated phosphorus movement to surface waters. The increased infiltration that can result from no-tillage may increase the potential for water percolation and downward movement of nitrate, particularly in medium- and light-textured soils where rainfall capture exceeds the soil water-holding capacity.

Depth to the water table is important, since shallow water tables are more prone to nitrate contamination than deep ones. Where water table contamination is a potential, split applications of nitrogen are beneficial, along with other nitrogen best management strategies.

Under unirrigated conditions, intensifying the cropping systems to minimize or eliminate fallow periods reduces leaching. During long fallow periods, the water-holding capacity of the soil may be exceeded, allowing water and nitrate to move below the root zone toward the water table. Under proper fertilization programs such intensification also lowers residual soil-nitrate levels. Soil-profile nitrate testing is a good management tool for evaluating the effect of nitrogen fertilizer management programs on potential nitrate movement to the groundwater.

Another effect of increased surface residue is that of increasing the amount of mineral nitrogen, including nitrate, tied up in the newly formed soil organic matter, thus decreasing the level of nitrate immediately available for crops. If high residual soil-nitrate levels are found, nitrogen fertility management programs should be modified to reduce them.

References

- Olson, R.V., and R. Ellis, Jr. 1982. Iron. In A.L. Page, R.H. Miller, and D.R. Keeney, eds., *Methods of Soil Analysis, Part 2*. ASA-SSSA Agronomy Monograph No. 9., pp. 308-310. American Society of Agronomy, Madison, WI.

Olson, S.R., and L.E. Sommers. 1982. Phosphorus. *In* A.L. Page, R.H. Miller, and D.R. Keeney, eds., *Methods of Soil Analysis*, Part 2. ASA-SSSA Agronomy Monograph No. 9, pp. 416-418. American Society of Agronomy, Madison, WI.

Peterson, G.A., D.H. Sanders, P.H. Grabouski, and M.L. Hooker. 1981. A new look at row and broadcast recommendations for winter wheat. *Agronomy Journal* 73:13-17.

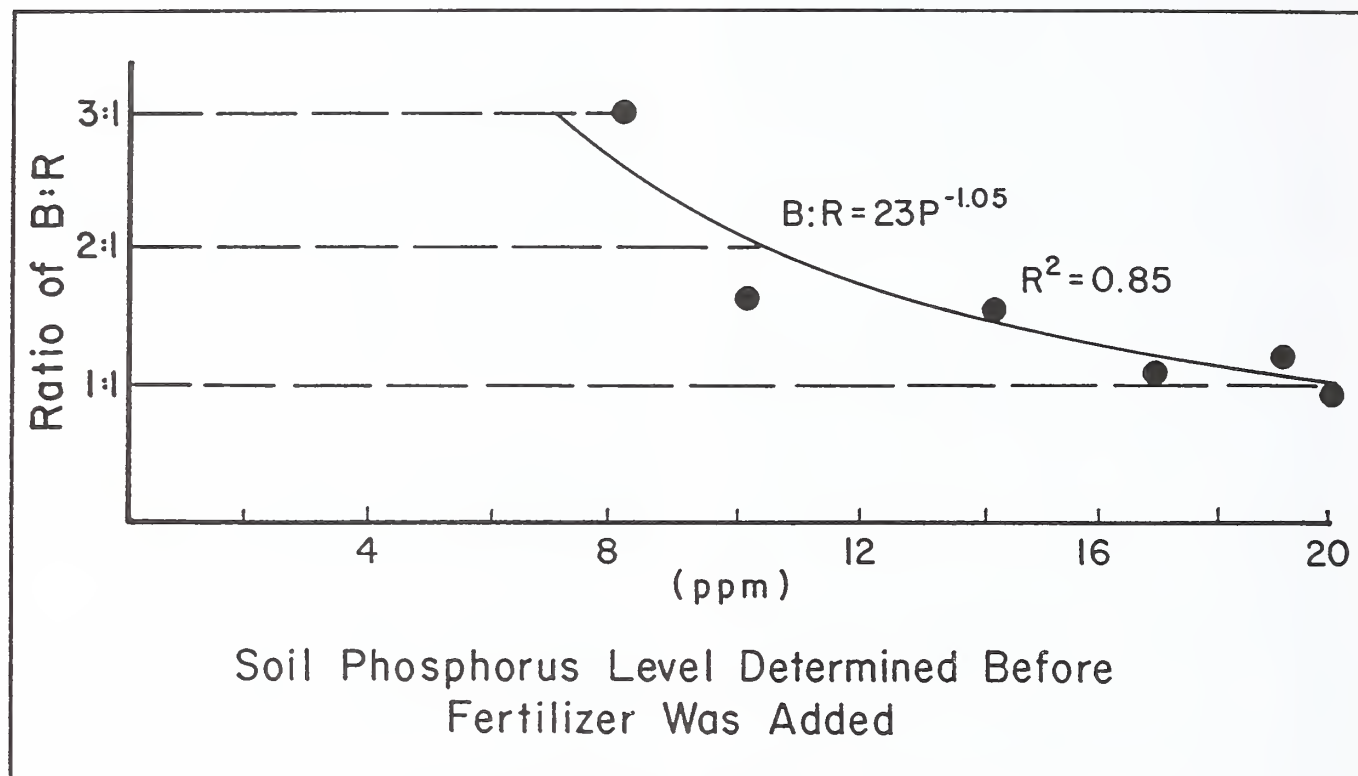


Figure 9. Relationship of phosphorus level (from soil test) and the ratio of broadcast and banded phosphorus fertilizer rates required to obtain an equal grain-yield response. Phosphorus levels determined by the Gray and Kurtz method (Olsen and Sommers 1982). (Adapted from Peterson et al. 1983).

10 Effects of Crop Residue Management on Water Quality

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Crop residue management affects the quantity and quality of water leaving a field either as runoff or percolation. These effects can be positive or negative depending on specific conditions. Research in the southern Great Plains has not shown any significant water quality problems because of crop residue management, although the phosphorus concentrations of some runoff waters and the nitrate concentrations of some shallow groundwater from fields with surface residues have been higher than those from conventionally managed fields.

This chapter presents information about water quality collected over the past decade from sorghum and wheat fields in the southern Great Plains. Where necessary for acceptable crop yields, fertilizer and pesticides were applied at recommended rates and times. Most attention focused on nitrogen and phosphorus, the two plant nutrients most frequently associated with impaired water quality.

Surface Water Quality

Table 13 shows mean annual runoff and soil and nutrient losses from dryland sorghum and wheat fields under different tillage practices. Results for associated native grasslands are included as baseline information and represent pristine conditions. Both reduced tillage and no-till were more effective in reducing soil losses than conventional tillage. For example, in El Reno, OK, the mean annual soil loss was 370 lb/acre for the no-till wheat field, compared with 8,930 lb/acre for the conventional-tillage wheat field.

Differences in surface water runoff were often slight among tillage practices at a particular location and exhibited no general trend. A notable difference, however, was observed at Bushland, TX, where mean annual runoff for reduced-tillage wheat was 0.5 inch, compared with 1.2 inches for no-till wheat. This difference, based on five wheat crops, is attributed to no disruption of crusted soil with no-till and reduced surface-soil-water storage capacity.

Irrespective of tillage practice, the net losses of soluble nutrients (nitrate-N, ammonium-N, and phosphorus) in surface-water runoff were small, frequently less than 1 lb/acre; often this level was nearly equaled or exceeded by amounts received from rainfall. A soluble nutrient is dissolved in the surface-water runoff. Compared with those for conventional tillage, the particulate nutrient losses for reduced tillage and no-tillage were low, typically below 5 lb/acre. A particulate nutrient is attached to or incorporated in an eroding soil particle. In general, reduced tillage and no-tillage were much more effective than conventional tillage in reducing particulate nutrient losses than soluble nutrient losses. Even so, from the standpoint of soil fertility, both

losses for reduced tillage and no-tillage are minor. Overall they reduced total nitrogen and phosphorus losses six- to seven-fold over conventional tillage.

Table 14 summarizes mean annual nutrient concentrations in surface-water runoff from the fields. In drinking water, nitrate-N levels below 10 ppm are considered acceptable for humans and below 100 ppm for livestock. Ammonium-N concentrations below 0.5 ppm are recommended for human consumption; concentrations above 2.5 ppm may be harmful to fish. The results indicate that mean nitrate-N values are well within acceptable limits and that mean ammonium-N concentrations are within or close to the limits.

In the case of phosphorus, soluble concentrations above 0.01 ppm and total concentrations above 0.02 ppm may accelerate eutrophication (depletion or disappearance of available oxygen) of lakes and impoundments. In agricultural lands of the southern Great Plains, both soluble phosphorus and total phosphorus concentrations exceeded these critical limits, even in runoff from unfertilized native grassland. Attempts to achieve or maintain concentrations below these thresholds appear to be unrealistic. It should be noted, however, that soluble phosphorus concentrations were sometimes higher with no-till. It also bears emphasizing that the concentrations presented in table 14 are annual averages. Higher concentrations may be observed for individual events, particularly if a hard rain falls shortly after the surface application of fertilizer.

Groundwater Quality

Groundwater results were obtained from wells installed at the El Reno, OK, site (table 15). The wells are typically installed in the direction of flow down the center of the field. Samples were analyzed for nitrate-N, ammonium-N, soluble phosphorus, and pH. Findings indicate elevated average nitrate-N concentrations of 13.3 ppm associated with no-till; 10 ppm is the acceptable limit. Moreover, the annual nitrogen concentrations increased from 5 ppm in 1983 to 20 ppm in 1990. Similar results were obtained at the Woodward and Perkins, OK, locations.

To determine whether nitrate-N was accumulating below the root zone, the no-till field at El Reno was sampled in 1-ft increments to a 6-ft depth. To date no evidence of a nitrate-N buildup has been found. Possibly, some nitrate-N movement to the groundwater is occurring by preferential flow, due to undisturbed large pores and a wetter soil profile with no-till. Remedial action may include more timely soil testing to better determine nitrogen fertilizer needs and more precise placement of the nitrogen fertilizer. The primary pesticides applied to the fields in table 13 included phenoxy (2,4-D), sulfonyleurea, glyphosate, and triazine herbicides. Through the years, occasional pesticide analysis of well water and of surface-water runoff have indicated no particular problems.

Table 13. Mean annual amounts of soil and nutrients lost in surface-water runoff from different fields

Location*/vegetation	Soil series	Field size (acres)	Slope (%)	Runoff (inches)	Soil loss (lb/acre)	Nitrate-N (lb/acre)	Ammonium-N (lb/acre)	Particulate nitrogen (lb/acre)	Soluble phosphorus (lb/acre)	Particulate phosphorus (lb/acre)
Prairie										
Bushland/shortgrass	Pullman	0.1	1	0.5	50	0.1	0.1	0.4	<0.1	<0.1
El Reno/tallgrass	Bethany	4	3	5.3	40	0.1	0.2	1.4	0.1	0.1
Woodward/midgrass	Woodward	14	8	0.5	140	<0.1	<0.1	0.3	<0.1	<0.1
Conventional tillage†										
Ft. Cobb/sorghum	Cobb	6	2	4.8	14,420	0.6	0.1	11.3	0.2	3.4
Riesel/sorghum	Houston Black	19	2	4.8	2,510	2.9	<0.1	4.6	<0.1	1.5
El Reno/wheat	Bethany	4	3	5.1	8,930	1.6	1.0	22.0	0.2	4.3
Woodward/wheat	Woodward	7	8	2.0	14,200	0.6	0.1	19.2	0.2	4.8
Reduced tillage†										
Bushland/sorghum	Pullman	6	1	0.8	460	0.4	<0.1	0.9	<0.1	0.3
Bushland/wheat	Pullman	6	1	0.5	200	0.8	<0.1	0.5	<0.1	0.1
Cyril/wheat	Norge	1	2	1.2	310	0.3	<0.1	0.6	0.1	0.2
No-tillage†										
Bushland/sorghum	Pullman	8	1	1.2	310	0.3	<0.1	0.6	0.1	0.2
Bushland/wheat	Pullman	8	1	1.2	300	0.5	<0.1	0.7	0.1	0.2
El Reno/wheat	Bethany	4	3	5.4	370	2.8	1.4	4.7	0.9	0.4
Woodward/wheat	Woodward	7	8	2.6	790	0.7	0.3	2.6	0.4	0.6

* Bushland, TX, is in the Southern High Plains; Cyril, El Reno, and Ft. Cobb, OK, are in the Reddish Prairies; Riesel, TX, is in the Blackland Prairies; and Woodward, OK, is in the Rolling Red Plains.

† Conventional tillage includes plowing (moldboard, chisel, or sweeps) and disking. Reduced till uses sweeps and maintains most crop residue on the soil surface. No-tillage involves disturbance of the soil surface only at planting.

Table 14. Mean annual nutrient concentrations (ppm) in surface-water runoff (flow weighted)

Location*/Vegetation	Nitrate-N	Ammonium-N	Particulate nitrogen	Soluble phosphorus	Particulate phosphorus
Prairie					
Bushland/shortgrass	0.5	1.2	3.2	0.7	0.1
El Reno/tallgrass	0.1	0.2	1.4	0.1	0.1
Woodward/midgrass	0.3	0.2	1.9	0.2	0.5
Conventional tillage†					
Ft. Cobb/sorghum	0.6	0.1	12.2	0.2	3.7
Riesel/sorghum	2.9	0.1	5.6	0.1	1.8
El Reno/wheat	1.4	1.1	18.1	0.2	3.5
Woodward/wheat	1.0	0.2	23.4	0.5	5.9
Reduced tillage†					
Bushland/sorghum	2.2	0.4	7.0	0.7	0.1
Bushland/wheat	3.0	0.1	2.1	0.1	0.6
Cyril/wheat	2.3	0.4	4.7	0.1	1.0
No-tillage†					
Bushland/sorghum	1.3	0.2	2.3	0.2	0.6
Bushland/wheat	1.8	0.2	2.5	0.2	0.7
El Reno/wheat	2.0	1.7	6.6	0.6	0.7
Woodward/wheat	1.5	0.4	4.7	0.5	1.0

* Bushland, TX, is in the Southern High Plains; Cyril, El Reno, and Ft. Cobb, OK, are in the Reddish Prairies; Riesel, TX, is in the Blackland Prairies; and Woodward, OK, is in the Rolling Red Plains.

† Conventional tillage includes plowing (moldboard, chisel, or sweeps) and disking. Reduced till uses sweeps and maintains most crop residue on the soil surface. No-tillage involves disturbance of the soil surface only at planting.

Table 15. Analyses of groundwater from field wells at El Reno, OK

Field	Nitrate-N (ppm)		Ammonium-N (ppm)		Soluble phosphorus (ppm)		pH	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Native prairie	1.5	0.0–6.6	0.3	0.0–5.9	0.10	0.0–0.3	7.6	6.6–8.4
Conventional-tillage wheat	1.4	0.1–8.8	0.1	0.0–1.4	0.03	0.0–0.1	8.0	6.4–8.4
No-till wheat	13.3	1.5–34.4	0.04	0.0–0.2	0.03	0.0–0.4	7.9	6.5–8.4

11 Soil Compaction and Bearing Strength

T.H. Dao, J.E. Morrison, Jr., and P.W. Unger

Compacted soil restricts water, air, and root penetration, thereby restricting crop growth. Compaction impedes drainage, which may limit the mobility of farm machinery and cause delays in field operations. As conservation tillage becomes more widespread and less tillage is used, researchers and potential users are concerned whether soil compaction will become a critical problem. Is compaction an acceptable production risk? Are there acceptable remedial techniques to loosen compacted soil while complying with conservation plans? This chapter considers these questions and discusses causes and effects of soil compaction in various production systems.

Several pressure-exerting processes cause soil compaction. These are discussed next.

Natural Consolidation

Natural soil consolidation is a spontaneous process, causing primary soil particles to reorient themselves and pack together tightly while excluding air and water contained within. Puddling of an unprotected soil surface is a leading cause of structural breakdown and consolidation. Loss of soil organic matter also enhances soil consolidation. Natural consolidation can be minimized with sound management practices that improve soil structure.

Compaction from Tillage and Wheel Traffic

Soil Density and Bearing Strength

Soils differ in their susceptibility to compaction. Clay soils become compacted with one-third to one-fourth the pressure it takes to compress sandy soils, as shown in the following example:

Soil texture	Bearing capacity at 80% water-holding capacity (lb/inch ²)
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Sand	27-32
Sandy loams	18-24
Clay loams	10-17
Clay	6-8

Mechanically caused compaction of the tilled layer (6-8 inches) differs from compaction of the deeper subsoil. Shallow compaction is caused by the pressure of tillage equipment and pressure on the tire tracks as loaded wheels roll over the surface. Shallow compaction may be alleviated by primary tillage. Research indicates that the degree of

compaction varies with axle load, irrespective of the number or type of tires used on the machine. Compaction caused by axle loads in excess of 4 to 6 tons, for example, may extend deeper than the operational depth of subsoilers or paraplows. Tillage to shatter deep restrictive layers requires large amounts of energy and high-draft tractors.

Approximately 80-120 percent of a field is covered by wheel tracks from the period of field preparation through harvest. A vicious circle is established as tillage is required to loosen compacted soils and prepare fields for growing the next crops.

Compaction from wheels and the general consolidation of tilled soils can be minimized by (1) reducing the number of trips over the field; for example, by adopting some form of conservation tillage; (2) using low-draft implements and matching lightweight tractors when soil conditions are compactible; (3) using four-wheel drive rather than dual rear-wheel tractors to reduce the compaction area; and (4) row-cropping with permanent traffic lanes to allow the soil between lanes to remain uncompacted for optimal root growth and crop production.

Soil Water

Soil-water content is a consideration in deciding when to till to avoid puddling and compaction. Wet soils are highly vulnerable to compaction; their maximum density generally occurs when the soil-water content nears field capacity, that is, at the field-water content about 1 to 2 days after a rain.

No-till fields generally have a higher bearing strength than tilled fields, particularly recently tilled fields. This fact becomes important during the first few days after a rain if time-sensitive field operations need to be performed. For example, a farmer can spray, seed, or harvest no-till fields sooner after a rain than tilled fields because tilled fields cannot bear the traffic. And the wait is longer with greater amounts of rainfall. Being able to get to the field and seed the crop a few days sooner makes more efficient use of the rainfall and often results in a better stand.

Many soils in the southern Great Plains are low in organic matter, and their surface dries rapidly under high wind and temperature conditions. The wetness or dryness of the subsurface layers, however, depends on soil type. A soil's bearing strength also varies with the time of year. Processes that regenerate soil bearing capacity change with the climate of the Major Land Resource Areas (MLRA's) along the north to south and east to west transects. In the northern MLRA's (H and G; see map inside back cover), freezing and thawing of moist soils help reduce soil bulk density. In the southern MLRA's (southern regions of H, I, and J) the predominant regenerative processes of soil structure are alternate wetting-drying and shrinking-swelling rather than freezing and thawing.

Soil Carbon

By exposing soil particles and colloidal materials to oxidation in air, tillage increases the mineralization of soil nutrients—in particular nitrogen—that enhance crop yield. This mineralization encourages additional tillage. Because of cultivation, the organic matter in soils is in continual decline, and the soils are subject to many other forms of chemical and biological deterioration.

In contrast, conservation tillage maintains plant residues intact or incorporates them to a shallow depth, lessens the oxidation of soil organic matter, and reduces soil compaction. After a decade of continuous no-till winter wheat cropping at El Reno, OK, significant increases in organic matter were measured in the near-surface zone (0–8 or 12 inches), which improved the soil structure and bearing strength (fig. 10). The surface of the no-till soil remained firm but friable. Soft seedbeds were prepared only in the seedrow instead of fluffing up the whole field. The moist, undisturbed interrow zone provided a stable anchor for seedlings and a carbon-rich growth medium for micro- and meso-organisms that decomposed crop residues. Decomposition released by-products and cementing agents that are generally beneficial in forming and stabilizing soil aggregates and in preventing surface crusting.

Crops

Crops that produce a large quantity of residue such as corn, sorghum, small grains, and most cover crops quickly add raw organic matter to soils. The extensive fibrous roots of grass crops have a strong aggregating effect as opposed to the relatively coarse, sparse roots of crops such as sorghum or cotton. If undisturbed, crop roots provide a temporary fabric that helps retain soil structure and increase subsurface organic matter. Old roots decay in place and intact channels stay open to aerate the soil and help conduct water. Roots are particularly important for crops such as cotton that leave sparse surface residues after harvest.

Crop rotations promote and maintain good soil structure through the granulating effect of different root systems, the protection of the soil surface by different plant canopies, and the production of a wide array of organic materials that enhance biological activity and diversity. In planting it is preferable to use narrow-row rather than wide-row technology. Drill openers form a dense network of parallel microseedbeds, providing many sites for water and air to enter the subsurface. Narrow rows also mean increased plant-root density. And, narrow rows give crops a competitive edge over most annual weeds, resulting in fewer cultivations or passes of spray equipment for weed control.

Compaction in Mixed Cropping and Livestock Production Systems

Animal traffic causes shallower compaction of soils than farming equipment does. The area trampled by livestock may be more extensive, however. Trampling occurs for extended periods of time under varied climatic and soil conditions, causing a substantial increase in soil bulk density when compared with that of ungrazed lands. The susceptibility of field soils to compaction varies with animal species, grazing management, stocking rate, soil type, seasonal climatic conditions, and vegetation or crop types.

Animal Species

Trampling degrades soil structure by the churning action of hooves under a load that depends on the species. Stocking rates can range from 300 to 800 lb/acre initial live weight. Trampling occurs with grazing and follows no consistent pattern, although grazing behavior differs among species. Sheep graze standing vegetation closer to the soil surface than cattle. In a closely grazed field, the soil surface is more vulnerable to erosion, more prone to compaction, and apt to smear and seal.

Vegetation and Seasonal Variations in Climate

Drought-resistant crops such as sorghum are well adapted to dryland production in the high plains where they are often rotated with cotton. Not all areas of the southern Great Plains are dry, however. Intense spring rainfall often causes soil crusting, and hail or blowing soil may damage young cotton and sorghum seedlings. At the end of the growing season, ruminant animals are allowed on the field to forage standing stubble. A compacted but dry soil during the fallow period can sustain heavy loads with less deformation than that sustained by moist soils during the growing season.

In winter wheat regions, undependable autumn rains affect plant establishment. Intensive tillage aggravates soil-water deficits at wheat planting because the soil dries after tillage, resulting in sparse wheat pastures. Under reduced tillage or no-till, higher soil-water content at planting allows early seeding. When planted strictly for grazing, the wheat plant has the advantage of more time to develop with the result that it is better able to withstand defoliation, since the grazing crop is seeded about 4–6 weeks before a grain crop. Since defoliation from grazing increases tillering, grazed wheat crowns provide some soil coverage and support for animal traffic.

Grazing Management

In large areas of MLRA's G and H (see map inside back cover), livestock are released in wheat pastures early in a crop's growth cycle. It is not uncommon to find animals in the field when wheat is in the two- to three-leaf stage, particularly in years with dry autumns. Measurements of pressure exerted by mature cattle under static conditions average 25 lb/inch²

(0.17 megapascals). However, as the cattle move, the pressure they exert can be four times as much, as each animal distributes its weight from one hoof to another. Bulk densities of 87–100 lb/ft³ (1.4–1.6 g/cm³) are commonly measured under hoof prints left by 300- to 500-lb cattle in tilled fields. By the end of the grazing period, the top 4–6 inches of soil are compacted regardless of whether the field was plowed, stubble-mulch tilled, or no-tilled (fig. 11).

The trampled surface of a no-till field has a high bearing strength. Some recommend plowing or cultivating no-till fields every few years to loosen the soil. Many studies indicate that soil with high mechanical strength reduces the number and depth of roots. However, penetration-resistance measurements can mislead by giving the impression that roots cannot overcome the firmness of no-till soil. Soil-strength measurements, for example, cannot detect fine cracks, convoluted fine-root channels, and small-diameter wormholes in the soil. Macroporosity of the soil subsurface is maintained through shrink-swell, freeze-thaw, and heaving that create small fissures and planes of weakness. Weathered plant crowns or stubble keep the surface open and connected with the root channels underground. Although these biopores represent less than 1 percent of the bulk soil volume, roots of subsequent crops utilize these pathways of low resistance. In fact, stubble-mulch and no-till practices increase surface-soil porosity; soil bulk density is less variable throughout the growing season and is lower than that of plowed soil of cropping systems without the livestock component (fig. 11). Because soil consolidation occurs rapidly after mechanical tillage, to follow the recommendation to periodically plow no-till soils would destroy the benefits that accumulate with time and would accelerate the oxidation of organic matter.

In years when wheat graze-out is practiced, livestock are not removed from the field to allow grain development. Trampling thus occurs over a longer and wetter period. Chiseling is often recommended to producers who practice conservation tillage to break up compacted soil layers after grazing. (Producers who till intensively continue to use the plow and disk.) The firm no-till soil surface resists soil deformation and aggregate breakdown under grazing. At least once a year, the drill opens the soil surface when the wheat crop is planted. The action of hooves kneads crop residues into the soil, lessening the smearing and sealing of the soil surface, and the flattened mulch reduces the impact of raindrops.

For the last 8 years of research, soil compaction caused by grazing has not been excessively detrimental to wheat crops under continuous stubble-mulch tillage and no-till, a condition unlikely to change in the near future. However, high stocking rates (more than 300–350 lb/acre in the fall and 2,500–3,000 lb/acre in the spring) cause greater soil compaction. The combination of no-till and grazing stretches the grazing season at both ends, yielding more

grazing days than do conventional production practices. So, stocking rates must be managed to avoid overstocking.

Indications of and Remedies for Soil Compaction

Conservation tillage provides promising production alternatives, but they demand a high level of managerial skill and are less forgiving than conventional practices. Farming operations may have year-round effects. The effects of past-year cropping practices may affect the current growing season and possibly following growing seasons, too. Accordingly, soil, plant, and pest conditions should be scouted on a regular basis.

Soil compaction is often reflected by one or more of the following symptoms:

- poor plant growth—variable plant height due to variable seedling emergence; wilted plants due to limited root penetration;
- shallow root system—more lateral than downward growth;
- lodging—shallowly rooted plants are not well anchored;
- standing water due to reduced infiltration;
- very dry spots in field; noticeable wheel tracks; and
- excessive soil erosion because of reduced infiltration and increased runoff.

There are several corrective procedures to alleviate soil compaction and remain in compliance with a conservation plan. They include

- timing essential field operations to the soil-water content;
- using controlled traffic lanes for tillage and harvest equipment and tractors;
- adjusting livestock stocking rates;
- using rotational grazing practices;
- using various crop types (for example, rotating fibrous-root-system crops and deep-root-system crops) to alleviate mechanically induced impedance to seedling roots;
- planting leguminous cover crops to build up nitrogen and organic matter;
- using soil amendments, such as manure, gypsum, and lime;
- increasing the activity and populations of earthworms whose burrows provide pathways for roots, water, and oxygen, even through relatively dense and compacted soils. No-till leaves the burrows intact and provides a more continuous supply of worm food, moister soil conditions, and protection from temperature extremes.
- using narrow-row cropping methods and crop residue management practices to hasten the development of canopy that protects the soil surface, to control weed growth, to minimize secondary tillage, and to avoid pulverizing soil;
- using tillage that leaves more residues on the surface (such as paraplow, vertical tillage, sweep, and deep chisel) if soil becomes too tight to maintain yields.

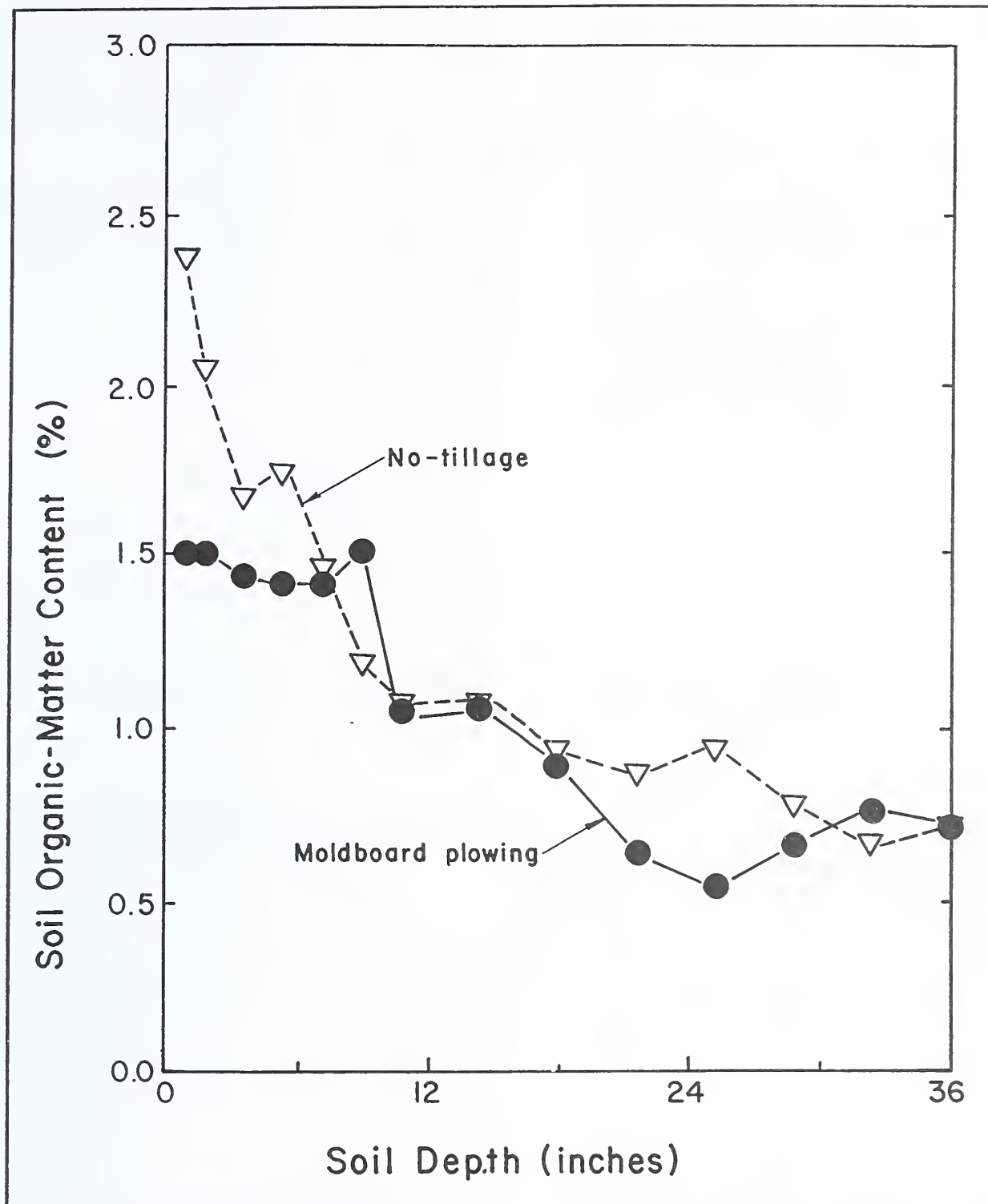


Figure 10. Effects of tillage method and depth on soil organic matter in a Bethany silt loam after 10 consecutive years of crop residue management at El Reno, OK

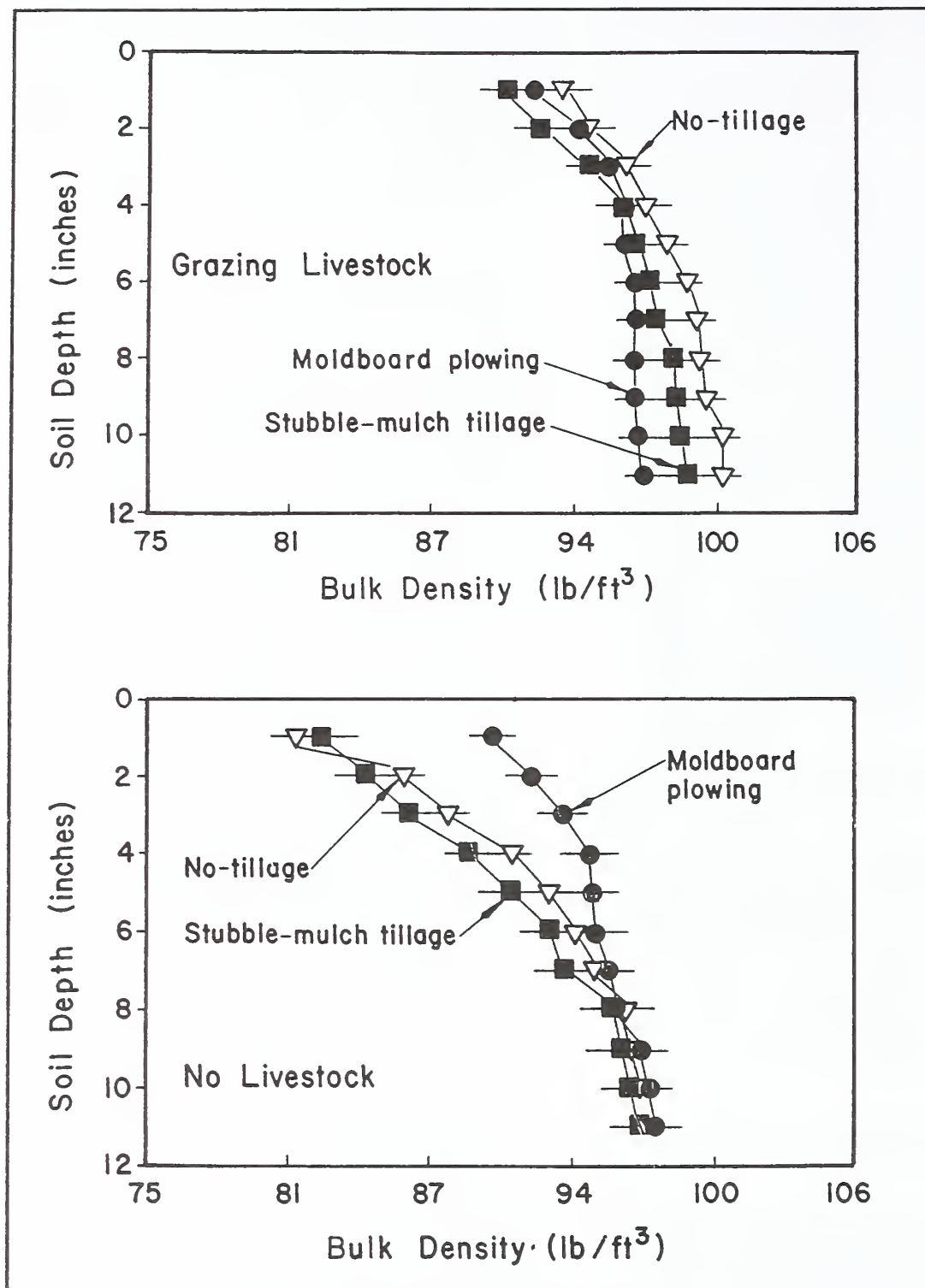


Figure 11. Effects of tillage and crop residue management on soil bulk density after 8 consecutive years of management with grazing livestock present November–March and without livestock present

12 Weed Management

Monte Toombs, R.L. Anderson, Paul Baumann, and Wayne Keeling

The control of problem weeds is important in any crop production system. Prior to the 1950's, weeds had to be controlled on cultivated land either by tillage or some other mechanical means, such as hoeing or pulling by hand. During the 1950's, the first herbicides were introduced on the U.S. market. The development of selective herbicides created new opportunities for crop residue management that were never economically feasible before. Great strides in the development of selective herbicides were made in the 1980's that revolutionized tillage systems.

The idea of combining several weed-control methods—known as integrated weed management—was also introduced. Integrated weed management includes control of existing weeds, prevention of weed seed production, use of soil-applied herbicides to control weed germination, and use of postemergent herbicides when needed. Crop rotations, crop competition, mechanical tillage, and biological control may also be part of an integrated weed management system. Considerations necessary for a good weed management program include the weeds present or expected, the crops to be grown, herbicide carryover to susceptible crops in the rotation, and economic comparisons of alternative control measures.

Discussed in the sections that follow are general guidelines for controlling some of the most prominent weeds in some of the major crops in the southern Great Plains.

Controlling Problem Weeds in Cotton

Weed control measures practiced in Texas and Oklahoma cotton are highly variable and depend largely on the area under consideration. Uniform recommendations are, therefore, nearly impossible except for small-seeded grasses and broadleaf weeds for which the dinitroanilines provide excellent control. However, these herbicides require mechanical incorporation and are, therefore, not compatible with some crop residue management systems. The exception occurs in areas where these products can be applied at elevated rates through sprinkler irrigation systems or applied to the soil surface shortly before overhead irrigation.

Managing weeds and controlling erosion with surface residues in cotton presents a formidable task. In the dryland production areas of west Texas, weed control through periodic cultivations may suffice, provided extended periods of rainfall do not occur early in the growing season, encouraging broadleaf and grassy weeds. However, in cotton in irrigated west Texas and in other areas of Texas and Oklahoma, a different situation exists. Broadleaf and

grassy weed infestations are too severe and cause great economic loss if only managed between rows with timely cultivation. Therefore, the use of herbicides is imperative.

In systems where cotton is planted into weed or crop residues and soil needs to be left undisturbed, reasonably effective broadleaf weed control can be accomplished in medium- to heavy-textured soils through use of the preemergence surface-applied herbicides such as fluometuron, prometryn, or diuron. Rainfall or irrigation needs to follow shortly after application to activate these herbicides. Since these herbicides provide very little consistent grass control, this problem needs to be managed with postemergence applications of herbicides such as sethoxydim, fluazifop-P-butyl, or clethodim (see table 16 for trade names). Perennial and annual weeds not controlled by the aforementioned herbicides should be removed by hand or herbicide spot treatments.

Letting weeds grow to maintain soil cover prior to planting might reduce wind and water erosion. However, production losses resulting from moisture removal and difficulties associated with managing the weeds before planting cannot be ignored. Systems such as those practiced in west Texas conservation tillage systems—where wheat is planted in the fall and its growth terminated prior to cotton planting—are generally more acceptable. However, this system is adaptable only in certain areas of the State and where specific irrigation equipment is available.

Controlling Problem Weeds in Grain Sorghum

Recommendations for weed control within grain sorghum cultures in the southern Great Plains vary greatly due to a wide diversity in soil type, potential weed infestations, dryland or irrigated cultures, and crop rotation schemes. Dryland grain sorghum production in the western low-rainfall areas is possible with minimal use of herbicides, provided extended periods of rainfall do not follow planting. Cultivation allows for removal of spotty weed infestations between the rows. In irrigated sorghum cultures and dryland sorghum in Texas, weed infestations require some herbicide treatment scheme. Preemergence herbicides must be applied in a band or broadcast to protect against annual grass weed infestations whether in minimum tillage or conventional systems. The herbicides atrazine or metolachlor and alachlor (in conjunction with safened seed) make up the options (table 16). However, use of these products on coarse soils will likely injure the crop plants. If broadleaf weeds are a potential problem, preemergence applications of these same products is an option, with the same precautions. An alternative would be to wait and see if broadleaf weeds become a problem, then utilize postemergent applications of atrazine, 2,4-D, or dicamba (if allowed). There are no herbicides available for postemergence grass control in grain sorghum.

The previously described weed control options can be employed in crop residue management systems, provided sufficient rainfall or irrigation is received soon after preemergence herbicides are applied. Crop residues alone may provide some weed inhibition; however, it is doubtful they would eliminate the need for herbicides. Weeds allowed to grow in the off-season to reduce wind and water erosion extract moisture that may be needed later at planting, and they require an herbicide treatment or tillage before planting.

Controlling Problem Weeds in Winter Wheat

The bromes (*Bromus tectorum*, *B. japonicus*, and *B. secalinus*), jointed goatgrass (*Aegilops cylindrica*), and volunteer rye (*Secale cereale*) are common weeds in the southern Great Plains and cause significant yield losses in winter wheat. Historically, producers controlled these weeds by plowing, thus burying the seed deep in the soil. Plowing, however, eliminates surface residue, which increases erosion. Fortunately for producers, other cultural practices are now available that reduce the impact of these weeds on winter wheat production.

This section suggests alternative control practices for these weeds during three periods of a conservation tillage production cycle: (1) during the wheat growing season, (2) before the next wheat crop, and (3) at winter wheat planting.

During the Wheat Growing Season

Mowing infested areas during the crop season can prevent seed production and reduce future infestations. If mowing occurs before the weeds flower, viable weed seeds will not be produced. Because grasses send up new tillers after cutting, it is also necessary either to spray or till the infested area to kill established plants.

Before the Next Wheat Crop

Options during fallow. Producers use sweep plows (blades) to control weeds in stubble-mulch fallow, but this method usually results in poor control of grasses. Adding mulch treaders to sweep plows improves grass control. To prevent plants from producing seed during the fallow period, it is crucial that the early spring tillage be effective. If a wet spring occurs, grasses can survive a sweep-plow operation. An option for producers in this situation is to apply glyphosate, which generally ensures that grasses do not flower and produce seeds.

Chemical fallow relies on residual herbicides applied after winter wheat harvest to control weeds. The herbicides prevent weeds from establishing during fallow and eliminate the need for tillage by maintaining residues on the soil surface longer.

By combining tillage and herbicides, producers can further reduce the weed seed population in soil (seedbank) before planting. Tilling once after wheat harvest incorporates weed seeds in the soil and stimulates germination; applying residual herbicides after tillage controls seedlings and prevents seed production. This fallow also maintains residues on the soil surface for protection from erosion.

Rotations. Crop rotation is an effective control measure. Planting summer annual crops between winter wheat crops lengthens the time between wheat crops, thus depleting the weed seedbank by germination or death. However, it is crucial that the grasses do not establish and produce seed during the period between crops. A secondary benefit of extended crop rotations is the production of more crop residue, resulting in more protection from erosion.

Planting-Time Options

Canopy structure. Any practice that reduces the amount of light which reaches weeds also reduces their growth and seed production. Examples of options include planting narrower rows, selecting taller varieties, and increasing seeding rate.

Delayed planting. Delaying wheat planting allows more weed seeds to germinate and emerge before the crop is planted. Producers can control these weed seedlings with tillage or herbicides.

Nutrient management. Banding nitrogen close to the wheat seed at planting favors the growth of wheat over the growth of weeds, which are farther from the nitrogen supply.

Herbicides. Diclofop and metribuzin will suppress downy brome in winter wheat. Because their performance has been erratic, especially in dry conditions, it is important to follow label recommendations to ensure effectiveness. Presently, no herbicides are available for control of jointed goatgrass or volunteer rye.

Using Annual Winter Weeds as a Cover Crop

Annual winter weeds can be used as a cover to protect the soil between harvest and planting of annual summer crops. However, because of the limited rainfall in the southern Great Plains, this is usually a poor alternative because the weeds compete for moisture with the crop. The objectives of this type of system are normally to control wind and water erosion. As residue from the previous crop decomposes over the winter months, annual winter weeds and grasses are allowed to grow so they can protect the soil surface from abrasive winds, disperse raindrop energy, and slow runoff. In order to control erosion the plants need to provide adequate cover from harvest until seedbed preparation for the next crop. Additional protection from erosion can be provided by planting the next crop directly into the weed cover. Because a favorable seedbed needs to be provided

and moisture needs to be conserved for the following crop, the winter cover should be killed with a burndown herbicide as soon as it develops enough mass for the needed protection. The tendency of vegetative cover to decrease surface runoff and increase infiltration partially offsets additional water usage by winter annuals.

This increased vegetation during winter months may take up available nitrogen supplies. And, nitrogen may still be tied up with the winter cover at planting time for the next crop. A "starter" fertilizer may thus be needed at planting to get the crop off to a good start. If deep percolation into groundwater is a concern, then having the nitrogen tied up during the off-season could be an added benefit.

Care should be exercised to prevent establishment of perennial and other hard-to-control weeds and grasses. Herbicides should be chosen that do not have a residual effect which prevents the winter cover from becoming established. If hard-to-control or perennial weeds become established, they can be spot treated if detected early enough. The limitations to using weeds as a cover crop over a small-grain cover would include nonuniformity of stand establishment, provision of less cover, and more difficulty in burndown of a mixed weed population.

Table 16. Generic names and trade names of pesticides used in the southern Great Plains

Generic Name	Trade name
Alachlor	Crop Star, Lasso, Micro Tech, Partner
Atrazine	AAtrex
Clethodim	Select
Dicamba	Banvel
Diclofop	Hoelon, Illoxan
Diruon	Direx, Karmex, Sprakil D-8 Granula
Fluazifop-P butyl	Fusilade 2000, Ornamec
Fluometuron	Cotoran, Meturon
Glyphosate	Accord, Militia, Polado L, Ranger, Rodeo, Roundup, Shackle
Metolachlor	Dual, Medal, Pennant
Metribuzin	Lexone, Sencor
Prometryn	Caparol, Cotton-Pro, Prometrex
Sethoxydim	Poast, Poast Plus
Terbutryn	Igran
Trifluralin	Treflan, Trific, Tri-4, Trilin
2,4-D	2,4-D, Weedone, Weed-Rhap

13 Insects and Diseases

*Robert Burton, Charles Rush, and
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With the adoption of crop residue management systems over large areas and many crops, it was generally assumed that insect pest problems would increase. This assumption was based on the fact that producers for generations used cropping practices like "sanitation plowing" to reduce pest insects, diseases, and weeds. While some pests do pose a greater threat under crop residue management, fortunately the systems have had little or no effect on most pest populations and even reduce the threat of some insect pests.

Deep moldboard plowing has been shown to destroy active and dormant insects by burying them and preventing their emergence or by mechanically exposing them to increased desiccation, freezing, and predation. However, researchers found that this destruction did not always correlate with reduced levels of insect pests in the subsequent crop, especially if the pests had alternate hosts or was able to disperse over wide areas. Researchers comparing crop residue management with conventional tillage often cannot make general inferences about how insects would respond to changes in tillage practices and find that each relationship among species, cropping system, and location should be considered on an individual basis. The relationships between tillage practices and pest populations appear to be very complicated and are still often poorly understood.

Altered Insect Habitats

Reduced tillage substantially alters the habitat of pests and beneficial insects above and below the soil surface. These alterations can cause insects to react differently than they would under conventional tillage. Probably the most important changes are less mechanical disturbance of the soil and more crop residue on the soil surface. Continuous plowing alters water infiltration, light reflectiveness, soil pH, nitrogen levels, subsurface temperatures, and organic matter. Above ground, reduced tillage can increase soil cover, enhance structural diversity, moderate soil temperatures, and change weed diversity and density. These changes may influence insect populations in a positive or negative manner. Additionally, there is a uniqueness to each site, year, season, soil type, cropping practice, and type of crop. As progressively less tillage is used over a wider area and over a longer time, the nature of each habitat alteration becomes more complex and the effect of reduced tillage on insects may become even more difficult to predict. Many of the alterations of habitat created by crop residue management simultaneously affect the insect pests and their natural enemies.

An example of a beneficial effect of crop residue management is the reaction of certain aphids to the highly

reflective surface surrounding the crop plant from increased residue on the soil surface and reduced soil disturbance. Greenbugs infest wheat and sorghum fields each year as they migrate. Reflective surfaces repel migrating greenbugs, substantially reduce their numbers, and can prevent serious outbreaks of the pest. Other aphids, leafhoppers, and whiteflies may react similarly. Surface residues also provide diverse, favorable habitats in the mulch-litter layer that promote an abundance and diversity of natural enemies, particularly spiders and soil-dwelling predators.

Some fallow fields under reduced tillage produce more weeds and grasses that favor increases of such pests as cutworms, billbugs, and southern corn rootworms in several crops. Some resident pests such as soil insects are also potential problems in conservation tillage fields, but these problems are generally localized and sporadic. The proper use of herbicides, insecticides, and seed treatments can help manage many pests.

In fallow wheat fields under reduced tillage, more volunteer plants may appear, especially during wet years. Volunteer wheat provides habitat for two important pest species: the Hessian fly and the wheat curl mite. Populations of Hessian fly and wheat curl mite, a vector of wheat streak mosaic virus, increase on volunteer wheat during the summer and move to newly planted wheat in the fall. Normally solved by tillage under conventional systems, volunteer wheat and weed problems can be controlled under reduced tillage by using appropriate, properly timed herbicides.

Managing Insect Populations

Effective management of insect pest populations involves the extensive use of preventive tactics. The stability of crop residue management agroecosystems presents new opportunities for managing pests that are not available with conventional tillage systems. With conservation tillage, pest management systems can be modified and regulated without the abrupt interference of the plow or the extensive use of insecticides. Crop residue management cropping systems that are detrimental to or do not promote insect pests should be expanded into integrated pest management systems through the use of preventive techniques such as altered planting dates, resistant cultivars, other cultural (inhibitory) controls, and natural enemies. If residues are a problem because they harbor insects, other alternatives to conventional tillage, such as mowing and crop rotation, may be just as effective.

In some instances, insecticide treatments may be the only alternative. This suppressive action should be considered only when other tactics are not economically feasible and when pest populations exceed economic thresholds. Beyond the expense of insecticide treatment, considerations should include effects on the environment and destabilization of the agricultural ecosystem, which could amplify other pest problems.

In the future, insecticide use for pest control may decrease because of escalating costs of chemicals and their application, the increasing scarcity of effective compounds, and insect resistance. These problems amplify the need for more preventive controls, such as effective integrated pest management systems, and for a better understanding of the interactions between tillage and pest populations.

Disease

Farmers are questioning how crop residue management systems will affect disease development. It is difficult to answer this question. The three main components of any disease are a susceptible host, a virulent pathogen (a disease-causing organism), and environmental conditions conducive for development. These make up the so-called "disease triangle." In most instances, even when virulent pathogens are present in a field, the three disease components are balanced in favor of the host crop, so no disease develops. Although disease can result from a simple change of a single component in the disease triangle, such as introduction of a susceptible host, disease usually results from a shift in the complex interactions between host, environment, and pathogen. An example of such a shift is the switch from conventional to crop residue management, which directly alters the environment and may directly or indirectly affect host crops and plant pathogens. The balance among these interactions eventually determines how crop residue management affects disease development.

Foliar Pathogens

Coverage of at least 30 percent of the soil surface with residue creates a very different environment for host and pathogen than that of conventional tillage systems, where residue is burned, buried, or removed. The presence of surface residue has the greatest potential effect on diseases caused by foliar pathogens. Standing stubble or other types of crop residue provide a readily available food source for foliar fungal pathogens. The increased humidity near ground level often associated with crop residue creates a microenvironment conducive to fungi, which can colonize and produce millions of spores. These spores, spread by wind and rain, represent a tremendous threat of disease, especially on farms in humid areas with continuous production of susceptible crops. Anthracnose of corn and sorghum, northern and southern corn leaf blight, tan spot of wheat, and early blight of peanuts are examples of foliar diseases that are often more severe in conservation tillage systems.

Soil-Borne Pathogens

Crop residue management also affects soil-borne pathogens, only indirectly, by altering the soil microenvironment. Soil physical factors such as organic matter, nutrient availability, moisture-holding capacity, structure, and strength all

directly influence plant growth, which in turn can directly affect a pathogen. Seedling pathogens and the diseases they cause are especially sensitive to environmental changes in the soil. For instance, most agricultural soils are infested with fungi that are potentially pathogenic to emerging seedlings. With crop residue management, soils are typically wetter and cooler than with conventional tillage. These conditions slow seedling emergence, thereby increasing susceptibility to pathogens such as *Pythium* and *Rhizoctonia* spp.

These same pathogens are rapid colonizers of crop residues, and incorporation of residues can increase pathogen populations, as in the case of cotton and wheat residues and pathogenic *Pythium* populations. No increase occurs, however, when wheat residue is allowed to weather before incorporation. Colonization of residue by plants that live on nonliving organic material (saprophytic foliar microorganisms) inhibits subsequent *Pythium* colonization after residue is incorporated into the soil. This example illustrates the complexity of seedling diseases and tillage systems and the dynamic nature of the relationship. Both crop residue management and conventional tillage offer certain advantages and disadvantages. Which system a grower adopts often depends on his or her general attitudes about farming and options for disease management.

Root Rot

Depending on what crop is being grown and the pathogens present, conservation tillage can reduce, increase, or have no effect on disease incidence and severity of root rot. In a 3-year study at Bushland, TX, researchers found common root rot of wheat was less severe with conservation tillage than with conventional tillage. Populations of the pathogen were also higher with conventional tillage. Common root rot is more severe under environmental conditions that cause plant stress, such as dry, hot soils.

It seemed reasonable that disease severity would diminish under improved crop residue management systems because soils remain cooler and wetter, resulting in less plant stress. This same principle can be applied to any other disease that is exasperated by plant stress, such as charcoal rot of corn, sorghum, and soybeans; fusarium foot rot of wheat; and fusarium wilt of sugar beets. Soil conditions created by conservation tillage are generally more favorable for plant growth than those of conventional tillage. Therefore, even if plants are infected by pathogens, it stands to reason that a reduction in environmental stress can result in fewer overall losses from disease. The concept that plants can survive and prosper in the presence of potentially damaging pathogens when environmental conditions favor the plant is important.

However, just as soil-borne disease can be limited by conditions that favor the host, disease can increase in severity if the environment is highly favorable to the

pathogen. Take-all of wheat is a good example. The fungus that causes take-all colonizes the roots and lower stem of infected wheat plants but is a relatively poor saprophytic competitor. With conventional tillage systems that bury residue, the fungus does not survive well and so the disease diminishes the following year. With conservation tillage, however, the lower wheat stem remains above ground, allowing the fungus to survive and more disease to develop.

Disease Control

While ecologically and environmentally sound, conservation tillage systems are not always the best choice if additional strategies to control disease are not employed. With appropriate strategies, many problems of disease associated with conservation tillage can be overcome.

The first fact growers must know is the exact pathogen causing the problem. Trained personnel, such as extension agents and crop consultants, can help diagnose diseases.

Second, cultural practices that favor optimal growth and development of the host are critical in conservation tillage systems. For instance, planting date greatly influences crop performance. Planting warm-season crops, such as cotton and sorghum, in cold, wet soils is a sure invitation to seedling disease and stand-establishment problems. Likewise, planting cool-season crops, such as winter wheat, in warm soils encourages infection by *Bipolaris* and *Rhizoctonia*, pathogens easily avoided by planting winter wheat in October when soils are cooler.

Crop rotation is also very important in reducing disease pressure. In the southern Great Plains, many growers plant winter wheat in August for maximum forage production, heavily graze the wheat through April, plow up the stubble, and then plant again in September for a grain crop. Others plant a summer crop, such as corn or beans, after plowing out grazed wheat but plant wheat again in the fall. Neither continuous-wheat system allows a sufficiently long wheat-free period to reduce populations of wheat pathogens.

Growers should always plant disease-resistant or disease-tolerant cultivars that are well adapted to their area. A cultivar with high genetic resistance may be more susceptible to disease if planted in an unfavorable environment than a cultivar with less genetic resistance planted in a proper environment.

When disease pressure is exceptionally high, fungicides may be required, particularly with foliar diseases. Numerous foliar fungicides are available that are highly effective against specific pathogens. However, timing is critical for cost-effective application. Seed-treatment fungicides should always be used wherever possible; they are highly effective, are environmentally safe because of the extremely low volume of chemical required, and are generally a bargain

when weighing cost against potential benefit. Regardless of which tillage system is used establishing a vigorous stand is perhaps the most important phase in producing a healthy crop.

14 Economics

Patricia E. Norris, Penelope L. Diebel, and Arthur L. Stoecker

About 75 percent of the acres subject to conservation planning requirements are now being managed by some form of conservation tillage. This suggests that the economic impacts of crop residue management are of particular importance. Some of the most important considerations for evaluating the economics of crop residue management are discussed here.

Off-Site Impacts

Eroded soil is the most significant of all nonpoint-source water pollution problems. About one-third of sediment damages are attributed to soil eroded from cropland. Table 17 presents damage estimates in specific regions of the United States. Damages to water-based recreation include costs to recreational fishing, boating, and swimming. Costs realized for water-storage facilities include reduced storage capacity, dredging, and construction of additional capacity in new facilities. Navigable waterway damages include dredging costs. Damages to freshwater and marine fisheries result in decreases in commercial fishing revenues. Flood damages include costs to urban and nonurban areas, as well as reductions in agricultural productivity. Costs for dredging and clearing drainage ditches are included, as well as operation and maintenance costs for irrigation systems impaired by sedimentation. Water-treatment damages include costs for treating municipal water supplies, costs incurred by municipal and industrial water users when materials in water damage pipelines and equipment, and maintenance and repair costs incurred by steam electric power plants to correct damages from excess sediment in water. Finally, irrigated agriculture incurs costs in the form of reduced crop yields when irrigation water has high salinity levels resulting from excessive runoff and erosion. Other off-site damages from wind erosion, such as air quality problems, are also important considerations, but these costs have not been quantified.

An economic analysis of erosion control weighs whether the benefits from implementing the activities equal or exceed the costs of the activities. Ribaud (1986) estimated off-site benefits in the way of reduced damages from 1983 soil conservation investments as \$32.6 million for the mountain states, \$18.5 million for the northern Great Plains, and \$108.7 million for the southern Great Plains. Total private and public costs of erosion control for that year, including implementation, technical assistance, and administrative costs, were estimated to be considerably larger.

On-Site Impacts

Technical improvements often mask the negative impacts of soil erosion on cropland. Improved crop varieties, more effective pesticides, and better nutrient management techniques improve crop yields at a more rapid rate than soil erosion reduces them. Research shows that yield reductions from erosion generally occur over a long period of time.

Nevertheless, on-farm benefits of erosion-control practices are often readily apparent. Such improvements are especially noticeable from reduced tillage practices that maintain crop residues on the soil surface. Careful management of crop residues can increase crop yields and reduce labor and machinery costs.

Economic factors that can influence the costs of reduced tillage systems and the short-run profitability of maintaining crop residues include

- changes in machinery and labor expenses,
- changes in pesticide and application costs,
- changes in interest expenses,
- changes in crop yields and associated harvest costs,
- changes in eligibility for commodity programs, and
- changes in management time and skills.

Changes in Machinery and Labor Expenses

Reductions in fuel use and machinery repairs are the major effects of limiting tillage and cultivation operations. Budgeting studies in the southern Great Plains show fuel and repair costs can decrease from 30 to 50 percent as tillage operations go from conventional tillage to reduced tillage (sweep or disk) to no-tillage.

Labor expenses also decrease as intensity of tillage decreases. Most studies find the labor requirements of reduced tillage systems to be approximately half those of conventional systems. Adding chemical treatments may limit any reduction in labor requirements, but more intensive cultivation with lower chemical input may also limit reductions in labor costs.

Changes in Pesticide Costs

Herbicide costs under reduced tillage are generally higher than those of conventional tillage. Adequate control of weeds is a critical factor in maintaining crop yields under reduced tillage. In most field studies, herbicide costs for continuous no-till sorghum and continuous no-till wheat were two to three times those for systems with more intensive tillage and cultivation. In cases where residue maintenance harbors insects and disease, additional pesticide requirements may further increase costs. However, pesticide requirements may decrease where crop rotations replace monoculture systems.

Changes in Interest Expenses

Interest expenses can represent a significant portion of operating costs and should not be overlooked when making cost comparisons between tillage systems. If total operating costs decline under a reduced tillage system, then so will the interest costs on operating capital. Similarly, if machinery needs decrease so that ownership costs are lower, then so will interest expenses for long-term capital items. Some farmers who convert to no-till sell their largest tractors and gain sufficient operating capital to eliminate payment of interest funds borrowed for annual operating costs.

Changes in Crop Yields and Harvest Costs

Yield increases are attributed to better conservation of soil moisture and improved soil fertility. Where reduced tillage systems are combined with crop rotation, yield benefits are particularly evident. On the other hand yields can decrease with increased weed competition and insect and disease problems.

Tillage studies in Kansas found that yields from continuous dryland wheat were generally lower with reduced tillage. Continuous dryland wheat yields in Oklahoma are also lower when higher levels of residue are maintained. However, in wheat-fallow and wheat-sorghum-fallow rotations commonly used in the drier regions, wheat and sorghum yields increase with reduced tillage.

Texas researchers found that dryland wheat-fallow with reduced tillage averaged higher wheat yields than conventional tillage did. Yields of irrigated continuous wheat also improved with reduced tillage. Dryland and irrigated wheat-sorghum rotations in Texas had higher yields under reduced tillage, as did irrigated and dryland cotton.

When crop yields are higher, certain harvest expenses may increase. Custom harvest costs may go up, reflecting increases in the time and labor required. Hauling costs increase with higher crop yields. Where drying or other processing charges are involved, higher yields raise costs. If yields increase enough relative to expenses, then profits may be unaffected or even increase.

Changes in Eligibility for Commodity Programs

Crop residue management becomes an important economic consideration in that reduced tillage and increased residue on the soil surface help to assure compliance with soil conservation requirements and eligibility for monetary benefits.

When comparing costs and returns from conservation tillage systems, the producer should not factor in deficiency payments for tillage systems that do not provide adequate erosion protection of highly erodible land. In other words, returns calculated for reduced tillage systems, which presumably offer adequate erosion protection, should probably include deficiency payments. Returns from most conventional systems, except when other soil conservation measures are in place, may not automatically include deficiency payments.

While the receipt of deficiency payments is the most common benefit of commodity programs, it is critical to remember that other USDA program benefits are also jeopardized by failure to comply with conservation requirements. Production loan programs, crop insurance participation, Farmers Home Administration loan eligibility, and disaster assistance—all of which can be critical to a producer's financial situation—can be lost if the producer cropping highly erodible land is found to be out of compliance.

Changes in Management Time and Skills

One of the most significant components of successfully implementing a reduced tillage system is the more careful management required. Timing field operations, assessing pest pressures and treatment needs, and planning crop rotations can require significantly more time and skill than do conventionally tilled crops. Increases in time for planning and performing field operations should be included in any analysis of alternative tillage systems. Where there are needs for additional information and education, time requirements may be even greater.

Economic Analysis at the Farm Level

Partial budgeting is a technique for evaluating the farm-level economic impacts of changing to a crop residue management system. Switching to conservation tillage does not usually require changing everything done on the farm. Partial budgeting considers only the costs and returns that change with the reduced tillage plan.

A format for conducting a partial budget analysis is provided on the next page. Specific considerations include (1) changes in gross returns resulting from yield changes, (2) changes in operating costs, and (3) changes in commodity program benefits.

A. Change in Gross Returns

1. expected yield $\times$ price \$ _____ /acre

2. current yield $\times$ price \$ _____ /acre

(Subtract 2 from 1) $\longrightarrow$ \$ _____ /acre

B. Change in Operating Costs

1. total operating costs with new system \$ _____ /acre

2. total operating costs with current system \$ _____ /acre

(Subtract 2 from 1) $\longrightarrow$ \$ _____ /acre

C. Change in Commodity Program Benefits

1. deficiency payment with new system \$ _____ /acre

2. deficiency payment with old system \$ _____ /acre

(Subtract 2 from 1) $\longrightarrow$ \$ _____ /acre

Change in Net Returns (Calculate A - B + C) $\longrightarrow$ \$ _____ /acre

While the format does not factor alterations in longrun expenses, a different tillage system might cause producers to change machinery, as mentioned previously. If tillage implements are sold, ownership costs, including depreciation and taxes, could be expected to decrease. On the other hand, if a new grain drill is needed for planting in heavier crop residues, then ownership costs should also be assessed against the alternative system.

An example using the format is given next. A producer in central Oklahoma who is considering adopting a crop residue management system as part of a conservation compliance plan is currently using a conventional tillage system for continuous dryland winter wheat production. The conventional system consists of disking and moldboard plowing immediately following harvest, with an additional disking in early August and a preplant application of chlorsulfuron. The conservation tillage system under consideration is a sweep tillage system that consists of one

sweep tillage operation immediately after harvest and a second in August, with an herbicide application of 2,4-D in August. Conversion to the sweep system will assure maintenance of adequate surface residues for erosion control.

The producer expects the sweep system to reduce wheat yields by about 4 bu/acre, from 34 to 30 bu/acre. Machinery costs should decrease with the sweep system from \$18.71 per acre to \$10.29 per acre, while labor costs will fall from \$7.25 to \$5 per acre. However, an increase in herbicide requirements will increase chemical costs from \$2.41 per acre to \$5.61 per acre. Interest charges on operating capital are \$0.35 per acre lower for the sweep system. Crop residue maintenance will assure receipt of deficiency payments of \$34 per acre, which would be lost under the conventional system. The farmer enters these values into the format provided previously. Results indicate that the sweep system will return \$29.82 per acre more than the conventional system.

A. Change in Gross Returns

1. expected yield $\times$ price \$ 90.00 /acre

2. current yield $\times$ price \$102.00 /acre

(Subtract 2 from 1) $\longrightarrow$ \$ - 12.00 /acre

B. Change in Operating Costs

1. total operating costs with new system \$62.15 /acre

2. total operating costs with current system \$69.97 /acre

(Subtract 2 from 1) $\longrightarrow$ \$ - 7.82 /acre

C. Change in Commodity Program Benefits

1. deficiency payment with new system \$34.00 /acre

2. deficiency payment with old system 0 /acre

(Subtract 2 from 1) $\longrightarrow$ \$ 34.00 /acre

Change in Net Returns (Calculate A - B + C) $\longrightarrow$ \$ 29.82 /acre

The example does not include any change in ownership costs, nor does it account for other longrun changes in production or costs. For example, if continued use of the higher residue system results in a gradual increase in soil productivity, the yield deficit of 4 bu/acre might be reduced. Other factors not included in the format but important to a producer include the time required for herbicide application and how changes in tillage fit into the total farm operation.

Reference

Ribaudo, M.O. 1986. Reducing soil erosion: offsite benefits. U.S. Department of Agriculture, Agricultural Economic Report No. 562.

Additional Sources

Aw-Hassan, Aden, and Arthur Stoecker. 1992. Analysis of wheat tillage systems for long-term profitability and conservation compliance in Grant County. *Current Farm Economics* 65(2):13-29.

Conservation tillage research 1992. Kansas State University Agricultural Experiment Station Report of Progress 662.

Harman, Wyatt L. n.d. Economics of residue management in agricultural tillage systems. *In* P. Unger, ed., *Residue Management*. CRC Press, Boca Raton, FL. In press.

Table 17. Annual damages from eroded sediment from all sources for mountain states, northern Great Plains states, and southern Great Plains states

Type of damage	Mountain states*	Northern Great Plains*	Southern Great Plains*
Water-based recreation	\$133,600	\$ 57,200	\$301,200
Water-storage facilities	293,200	119,600	152,100
Navigable waterways	87,600	20,200	45,100
Commercial fisheries	200	500	54,400
Flood damages	104,000	56,100	84,600
Drainage ditches	31,900	32,500	24,100
Irrigation systems	29,400	2,500	8,200
Municipal water treatment	13,400	5,500	18,400
Municipal and industry water users	108,300	30,900	88,400
Steam electric power plants	1,300	1,500	1,100
Irrigated agriculture (from salinity)	9,900	2,700	7,000
Total damages	813,800	329,200	784,600

Source: Ribaudo 1986

* In the Ribaudo 1986 source that supplied the data for this table, the mountain states include Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, and Wyoming; the northern Great Plains states are Kansas, Nebraska, North Dakota, and South Dakota; the southern Great Plains states are Oklahoma and Texas.

15 Long-Term Effects of Tillage and Crop Residue Management

W.C. Moldenhauer, W.D. Kemper, and B.A. Stewart

The Beginnings of Soil Degradation

When Europeans arrived in America, they found soils that were a result of climate and vegetation interacting with the geologic minerals. Leaves and other residues fell to the ground and decayed, and part of their decomposition products leached into the soil. Roots grew, died, and decayed, also contributing to building the organic matter and associated elements that nurtured the natural successions of plants. Among these plants were legumes that provided photosynthate to bacteria infecting their roots which were able to take nitrogen out of the air, fix it in ammonium, and share it with their host plants. Primarily as a result of these legumes, about 6 percent of the residual organic matter in soils is now nitrogen. Other plant nutrients extracted from the soil and air and incorporated into the plants also became part of this soil organic matter. While most native Americans were crop growers, they were few in number. Their methods of crop production involved little tillage. Competing weeds were removed largely by hand.

Friendly natives taught the newly arrived Europeans how to grow corn in the early part of the 17th century. With their iron mattocks and hoes, the Europeans were able to control weed growth more efficiently than the natives. Within a few years corn was the staple of their diet, and they were growing enough corn to trade it to the natives for animal furs. Arrival of draft animals, cultivators, and plows gave the Europeans additional ability to control weeds. These implements also stirred and aerated the soil, buried crop residues, and stimulated microbial activity, which increased the breakdown of the residual organic matter, liberating its nutrients for use by the crops.

Since there were no commercial fertilizers, the accelerated decomposition of organic matter was the primary source of plant nutrients in those early years. The moldboard plow which turned the soil over completely, burying practically all of the crop residue, became the most popular implement for primary tillage. Complete burial of the crop residue and decreasing residual organic matter exposed soils to the beating action of raindrops, which destroyed soil aggregates, filled the large pores, and reduced infiltration, causing runoff and erosion. Erosion by runoff water carried away substantial portions of the topsoil in the eastern and southern portions of the country where rainfall rates were high. In the more arid western plains, burial of plant residues and subsequent beating from rain created smooth surfaces along which the wind blew the sand grains until they literally sandblasted the soil, enabling the wind to blow away major portions of our topsoils.

Early in the 20th century concerned farmers and government officials recognized the rapid degradation of our soils from erosion and initiated research and plans to reduce erosion. In the 1920's and 1930's, rotations, strip cropping, and mulch tillage were evaluated. These techniques involved blades that sliced under the surface and killed weeds but left most of the wheat stubble on the surface. They obviously helped reduce wind and water erosion. It took longer to observe their effects on soil organic matter content and fertility. Long-term studies were initiated at several locations across the country. At Urbana, IL, the Morrow experimental plots were established in 1876 to measure cropping effects and have been operated continuously ever since. They indicate that soil organic matter was about 6 percent when European Americans began tilling them. Continuous corn, involving plowing each year, has reduced the organic matter content to less than 3 percent (fig. 12). The best rotations reduced the rate of depletion and legumes in those rotations helped maintain soil fertility, but levels of organic matter still continued to decline as long as plowing continued.

At Pendleton, OR, the organic matter content in residual soil under grass was also reduced under moldboard plowing, accelerating runoff, erosion, and loss of fertility. Consequently, in 1929, researchers began evaluating a series of crop residue management treatments ranging from burning the residues to plowing 10 tons of manure plus the crop residues into the soil each growing season. Refraining from burning slowed the decline of residual organic matter, and during the first 20 years the heavy manure addition each year seemed to slightly increase the organic matter content (fig. 13). However, over the past 40 years even with 11–12 tons of organic residue plowed into the soil each growing season, residual organic matter content has not increased (Rasmussen et al. 1989).

Reicosky and Lindstrom (1993) measured the carbon dioxide given off in fields for 19 days after wheat stubble was moldboard plowed, chisel plowed, disked, or left standing with no-tillage. As shown in figure 14, the amount of carbon oxidized was greatest in fields that were moldboard plowed. In 19 days as much carbon was oxidized as had been photosynthesized and incorporated into the residues and roots during the whole growing season. A large portion of the crop residue was not completely decomposed at the time. Consequently, it appears that easily decomposable portions of the fresh residue provided food to generate high microbial populations, which found access to residual organic matter in the plowed and highly aerated soil and oxidized substantial amounts of it out of the soil. When one realizes that microbes can oxidize a couple of tons of organic matter in 19 days following moldboard plowing, it is easy to see how the 12 tons plowed into the Pendleton, OR, plots could be oxidized each crop year for the past 40 years.

Other types of tillage resulted in lower biological oxidation rates than moldboard plowing (fig. 14). Their use is helping slow the rate at which residual organic matter is being oxidized out of our soils. However, during the 19-day study period, oxidation of organic matter from all of the tillage treatments was much more than that from the no-till treatment.

Effects of Reducing Tillage on Residual Organic Matter

Development of wide v-blade sweeps, rod weeders, and other equipment that disrupt the soil and undercut weeds while leaving most of the crop residue on the surface helped control erosion (Lindstrom et al. 1974). As relatively low-cost fertilizers became available in the early 1960's, however, it was no longer necessary to till and oxidize organic matter to release needed nutrients. Development of herbicides provided an alternative to tillage for weed control. As conservation-minded researchers and farmers saw the improved erosion control from leaving residues on the surface, they used these alternatives and reduced tillage. Some of them reasoned that growth of grain crops was now possible in systems more similar to natural ecosystems.

In these natural systems when vegetative growth is good and burning does not occur, the soils generally have continuous cover and protection from the forces of wind and water. The major obstacle remaining was getting seed through the surface residues and into the soil. Equipment companies helped develop coulters, seed placement devices, and press wheels that cut through the residues without disturbing them appreciably and pressed seed into good contact with the soil. Development of no-till drills and seeders provided an alternative to seedbed preparation, the other major purpose of tillage. With these alternatives available, thousands of fields were soon managed without tillage.

The erosion control benefits of no-tillage were immediately obvious. Researchers documented that no-till reduced erosion to 20 percent of that occurring under moldboard plowing systems and even eliminated it completely. By removing crop residues from some of their no-till plots and observing erosion during rainstorms, they found that absence of tillage, in addition to keeping protective residues on the surface, leaves the soil more cohesive and more resistant to the erosive forces of water. Measurements in laboratories showed that bonding forces between soil particles decrease with tillage and increase with time following tillage. Root fabric and the high residual organic matter content that develops in the immediate surface under no-till reduce slaking and disintegration of aggregates when wetted.

In the past, scientists felt that incorporating crop residues into the soil was the way to get organic matter into the soils where it could become part of the residual organic matter. Reicosky and Lindstrom (1993) showed this intuitive

feeling was wrong. In fact, incorporating crops residues into the soil by moldboard plowing accelerates the rate of oxidation of both the crop residues and the residual organic matter, as discussed previously.

Farmers practicing no-till management are noticing their soils becoming darker. In Ohio, Georgia, Alabama, and Colorado measurements showed residual organic matter in no-till soils to be increasing. This increase has been greatest in the surface 2 inches, the zone most important for reducing slaking and for surface sealing (fig. 15). However, increased organic matter has been observed to depths of 4 inches in some fields where there has been no primary tillage for at least 10 years. Secondary tillage and incorporation of anhydrous ammonia in the soil cause some mixing of organic matter from the surface into the top few inches.

Water passing through organic residues into soils often carries over 100 ppm of dissolved organic matter, so 3 acre ft of water leaching through the residue could carry 1,000 lb/acre of organic matter into the soil. Decaying roots and matter exuded from roots also add organic matter at a rate of 1,000–2,000 lb/acre/yr. A major portion of this organic matter is used as an energy source by micro-organisms, but much of it is incorporated in their tissues and becomes part of the residual organic matter. Earthworms, burrowing animals, and insects also help mix organic matter from the surface crop residues into the soil.

Effects of Increasing Surface Residues on Residual Organic Matter

Measurements of residual organic matter in soils during 10 or more years of no-till management indicate increases ranging from 200 to 1,500 lb/acre/yr. The rate depends on how much crop residue is left on the surface. The highest rates occur where crop residues were augmented with winter cover crops left on the surface. The lower rates were from dry, warm regions where the amount of crop residues was limited and high temperatures caused rapid biological oxidation of the organic matter.

In areas where residual organic matter is low, organic wastes such as paper and manure have been placed on the soil surface or plowed into the soil to help increase the organic matter. The greatest sustained increases are resulting from leaving the organic wastes on the surface (Lu et al. 1994 a,b).

Elimination of tillage increases the amounts of organic residues on soil surfaces, decreases the biological oxidation rates of residual organic matter, and reduces soil erosion, all of which cause net increases in residual soil organic matter. No-tillage and reduced tillage can conserve our soils, but they can also enhance them so they will be able to sustain the world's population.

Effects of Leaving Crop Residue on the Surface

Effects on Soil Fertility, pH, and Rooting Depth

Fertility. One early concern about no-tillage was getting fertilizer and lime from the surface down to the crop roots. To some extent feeder roots solved this problem by nearing the surface where the soil was moister because crop residues had reduced evaporation.

Phosphorus was also expected to be a problem because it is normally adsorbed and relatively immobile in soils. However, as Kunishi et al. (1986) found, when left on surface residues, it apparently forms complexes with organic matter that leach into the underlying soil where they are readily available to feeder roots. Through mycorrhiza—the beneficial association of fungal mycelium with the roots of a weed plant—fungi extend their slim hyphae into the soil and allow plants to draw phosphate from those parts of the soil their roots cannot directly reach. More of these hyphal conduits remain intact when tillage does not occur. Crop roots in no-till soil tend to follow root channels of the previous crop; this enables the supplemental hyphal system to tie in more quickly, which helps the roots extract water, phosphorus, zinc, and many other elements from the soil.

pH. Calcium has historically been observed to stay close to lime placements in soils, raising questions about whether lime applied on the surface would stay there and leave the underlying soils excessively acid. Some of the early no-till researchers found that the immediate surface of no-till soils was becoming acid sooner when urea and ammonium-type fertilizers were broadcast on the surface. When lime was broadcast on the fertilized surface, it seemed to leave the surface more quickly. In long-term no-till fields where lime, crop residues, manure, and nitrogen fertilizer were left on the surface for 24 years, the acidity of underlying soils was neutralized to a depth of about 70 cm, compared with about 25 cm where soils were plowed and lime was mixed in (fig. 16).

The mechanisms by which the calcium in the lime is mobilized is probably influenced by the proximity of the crop residues, nitrogen fertilizer, and lime at the surface. As micro-organisms nitrify ammonium fertilizers to nitrates, acid hydrogen ions are produced that tend to solubilize the calcium in lime when it is close to the fertilizer. The slow and relatively continuous biological breakdown of the surface residues produces a continuous source of organic anions, which along with the nitrates facilitate downward leaching of the positively charged calcium, aluminum, and hydrogen ions in the soil. Researchers have been trying to get more calcium into subsoils for years because they recognize that raising pH caused subsoils to be more hospitable to roots. Deep plowing and mixing lime into the subsoil works but is too expensive. These benefits can occur

as a side effect of no-till as it leaves all the residues, fertilizer, and lime on the surface. When the nitrogen fertilizer is knifed into the soil, subsoil pH tends to increase, but this moderation of acidity is not as great as that noted when nitrogen fertilizer is applied on the surface.

Rooting depth. Sumner (1990) was able to increase alfalfa rooting depths in acid soils by 50 percent by getting calcium into subsoils with gypsum applications that left the subsoil undisturbed. Wang et al. (1986) found that earthworm burrows in the soil facilitated deeper rooting of soybeans. Since long-term no-till management generally increases earthworm populations and depth of calcium penetration, these two factors probably act together to facilitate deeper rooting. Deeper rooting provides the plants with access to more soil water. This access may help account for the increased drought tolerance of crops grown under long-term no-till management on fields that initially had acid subsoils.

In the drier regions of the United States where crop yields depend on stored soil water, proper residue management can increase soil-water supplies sufficiently to reduce the use of summer fallow. In order to take advantage of the additional water conserved, producers must change from crop-fallow to extended crop rotations with limited or no use of fallow. Additional fertilizer nitrogen is needed when the shift to no-till annual cropping systems takes place and nitrogen is being deposited as part of the increasing organic matter content of the soil. The quantity of nitrogen fertilizer needed may decrease after 10 years of annual cropping in minimum- or no-till systems as the residual organic matter becomes sufficient to supply more nitrogen for plant use.

Effects on Infiltration, Evaporation, and Water-Use Efficiency

The most direct and measurable effect of keeping crop residues on the soil surface is improving the water-use efficiency of acid and calcareous soils. In many areas the increases in infiltration rate and decreases in evaporation occur within a year or two, as discussed in previous chapters. However, in soils where earthworm populations are decimated by intense cultivation or harmful pesticides, it may take many years to bring the earthworm populations back so their burrows to the surface contribute significantly to infiltration.

In a series of small watersheds near Coshocton, OH, it took earthworms 6 or 7 years to return in large numbers after beginning no-till management (fig. 17). Results were obtained based on measurements of pores larger than 0.5 mm at the soil surface; earthworms and recent cultivation are commonly responsible for such large pores. Following cessation of cultivation, the percentage of the surface occupied by these large pores declined for 5 years. Only when the earthworms returned in large numbers were the large pores furnished that contribute to rapid entry of water in this soil.

Return of worms has been hastened by collecting buckets of them from lawns and edges of rural roads during or immediately following rains and depositing them in groups of four or five in new no-till fields. They will invade a soil at a rate of about 50 ft/yr when conditions are good for their growth. However, their lack of a specific urinary tract leaves urea on their skins, which hydrolyzes to ammonia and irritates them. Consequently, they are attracted to moist soils where they can quickly rub off the urea and ammonium and to the surface during rainfall events where the rain washes them off. Their tendency to come to the surface during rainfall events contributes to their migration during runoff, when they float downhill. On cloudy days when canopy cover is reasonably complete and at night, earthworms have been seen floating in tailwater out of furrow-irrigated fields in Idaho at rates of up to 50 per hour per furrow. In runoff plots at Kingdom City, MO, as many as 900 earthworms washed off a 945-ft² plot in a single rainfall event. While average rates of downstream transfer are generally lower than those given in these examples, introducing worms on the higher portions of a field can significantly increase their rate of return to the whole field.

As soon as crop residues provide cover for most of the surface for a significant part of the year, they help reduce evaporation from the soil. Long-term no-till practitioners report that the amount of crop residue returned to the field increases with time for 10 or more years as crop yields increase. However, some long-term no-tillers note that large populations of night-crawler-type earthworms collect residues in their middens, especially after soybeans, causing a more-rapid-than-normal removal of cover from the soil. Fortunately, this process does not usually reduce cover until the crop canopy has already begun protecting the soil from the impact of raindrops. Even when lack of cover allows a major portion of the soil surface to seal, several earthworm middens or holes per yd² drain most water accumulating on the surface into the soil, minimizing runoff.

In the more arid regions of the Great Plains most of the soils do not remain wet enough to sustain significant populations of earthworms without irrigation.

Effects on Crop Production

Factors that increase the units of crop produced per unit of precipitation include significant increases in infiltration, decreases in evaporation from soils, increased water-holding capacity, increased snow catch and deeper rooting associated with no-tillage, and retention of surface residues for extended periods.

High residual organic matter in soil also increases general fertility and productive capacity. In North Dakota, Bauer and Black (1994) quantified the value of soil organic matter to soil productivity on three sites. Each ton of organic matter was calculated to be equivalent to 31 lb of grain per acre. If

soil loss was 10 tons/acre/yr, then over a 50-year period 500 tons of soil would be lost. If this soil contained an average of 4 percent organic matter, then 20 tons of organic matter per acre would be lost over the 50 years. In this example, the loss in soil productivity therefore would be 20 tons of organic matter multiplied by 31 lb of grain per ton of organic matter, or 620 lb of grain per acre, or 10.3 bu/acre.

Soil organic matter acts as a "bank" where nutrients may be deposited in times of surplus and withdrawn in times when rainfall or irrigation leaches out most of the soluble and mobile nutrients, especially nitrates. Temporary nitrate deficiencies will not reduce crop growth nearly as much in soils with high organic matter content where micro-organisms are slowly and continually releasing nitrogen from the bank and making it available to the crop.

Residual organic matter, which derives from plants, includes most of the elements essential for crop production, and its slow decay provides a limited but continuing source of these elements. Slow decomposition of this organic matter also furnishes a host of organic molecules or fragments that act as carriers, enabling micronutrients absorbed in the soil minerals to reach the roots. Tillage accelerates the rate at which nutrients from crop residues and residual soil organic matter are mineralized or made available to crops. If the crop is not ready to use the nitrates, they are at risk of being leached out of the crop zone by rain. Like stirring the coals, putting in kindling, and opening the draft of a wood stove, tillage accelerates the oxidation of organic matter, liberating its components quickly to the surrounding environment.

Organic matter darkens soils because it absorbs more of the sun's radiation than the minerals do, and the soils are therefore warmer. Because crop residues reflect more of the radiation, covered soils stay cooler, which decreases plant growth in the cool early spring but may be better for crops in the late spring or early summer before crop canopies provide shade.

Farmers who want to increase the soil temperature around new crop seedlings to accelerate growth can use equipment on their tool bars to move residue off seed rows before or at planting time. Removal of the residue also permits continued use of conventional seeders for those farmers who do not own no-till seeders.

Effects on Erosion Control

Increased residue cover achieves substantial erosion control by (1) intercepting the impact of raindrops, slowing surface sealing, and sustaining higher infiltration; (2) causing water to pond on the surface, which causes wormholes and other macropores to become avenues for infiltration; and (3) causing settlement of sediment in the temporarily ponded water.

Refraining from tillage allows long-term mineralogical processes to strengthen bonding (somewhat similar to the processes that cause moist concrete to strengthen with time). Long-term no-till causes major increases in organic matter of the immediate surface soil so it is much more resistant to slaking and aggregate disintegration and has higher infiltration rates.

Reasons for Limited Tillage

Reasons for limited tillage include the following:

- In some cases the cost of a nutrient form, such as the anhydrous form of ammonia, is sufficiently lower than the cost of another nitrogen fertilizer to economically justify the limited cultivation needed to apply the ammonia.
- Deep chiseling or paratilling of soils to help crop roots grow past restricting layers benefits yields in some areas.
- As mentioned, ridge- or row-till equipment can push residues off the planting strip for row crops, allowing the use of conventional planting equipment and warming the soil to accelerate early growth.
- Under some climatic conditions weed and grain seeds need a light soil cover to help them germinate so they can all be killed by one herbicide application before a long fallow season or planting the next crop.
- In some special soils there is evidence that tillage can break the capillary pore connections between the soil water and the surface, thus keeping slightly more water in the soil during long, dry, hot summer fallow periods.
- During the initial 2 or 3 years of no-till, before sufficient soil cohesion has developed to support equipment weight, the soil may become so compacted and rutted during harvest in wet weather that tillage is necessary to break up the compaction and smooth the surface. (See chapter 11 for a fuller discussion of compaction.)
- Some state and regional regulations require burial of specific wastes and crop residues to control insects and diseases.

Each farmer must balance these benefits of cultivation against the damages. Since one moldboard plowing can oxidize as much organic matter out of a soil as can be accumulated by several years of high-residue no-till management, the benefits to be derived must be large to justify moldboard plowing. Other types of tillage that cause less oxidation should be considered when tillage is necessary.

One of the most critical factors that needs to be examined is the degree to which tillage will destroy soil cohesion, crop residue cover, and erosion control as computed by Soil Conservation Service (SCS) guidelines and equations. The economic consequences of failure to be in conservation compliance will be devastating for most farmers enrolled in government programs. Consultation with SCS technicians may help farmers avoid both the loss of erosion control and crop support payments.

Effects of Herbicides on the Environment

Concern has been expressed in some sectors that long-term use of herbicides for weed control rather than tillage will add manufactured chemicals to our soil, air, and water, thereby degrading them. A broad survey by Bull et al. (1993) indicates that producers who grow corn use about equal amounts of herbicides whether on tilled or no-till systems.

Most farmers recognize that herbicides are often the most cost-effective means to control weeds. In 1990 herbicide use on no-till soybeans averaged about 60 percent higher than that on tilled soybeans; by 1992 no-till averaged about 20 percent more. Long-term no-tillers say they are using less herbicide than when they started and often even less than when they were tilling. Because adoption of no-till is doubling every 3 years and only 25 percent of no-till farmers have a minimum of 6 years with the system, we anticipate that the amounts of herbicides used in no-till farming will continue to decline.

A factor that plays a significant role in herbicide contamination of water is the use of soil-incorporated (preemergence) versus direct-contact (postemergence) herbicides. Preemergence herbicides are the more common choice of conventional tillers. The most effective preemergence herbicides comprise chemicals that are mobile (not absorbed) in the soil and that persist for long periods before they degrade. Many of the postemergence herbicides, which are becoming the major choice in no-till management, are sprayed directly on the weeds, strongly adsorb (adhere) to soil if they miss their target, and rapidly hydrolyze or biologically degrade when they contact the soil.

Reduced tillage keeps topsoil on the land and out of streambeds, reservoirs, and lakes. Where no-till increases, better infiltration rates reduce flood damage, and increased groundwater recharge and base stream flows improve the environment. In monitored watersheds, where surface sealing from conventional tillage caused 10–30 percent of the precipitation to run off, long-term no-till often reduced runoff to negligible levels.

As water runs off, it carries feces from domestic and wild animals, disease organisms, and a host of organic compounds over 99 percent of which are of natural origin and less than 1 percent of which are of manufactured origin. Surface runoff that enters reservoirs is so heavily laden with contaminants that standard rapid filtration does not remove them all. Chlorination is commonly required to kill the pathogens before water can be used for drinking, but chlorination of humic acids and natural organic compounds can increase their carcinogenicity. When reduced tillage enables all precipitation to enter the soil, pathogens and other organic compounds filter out as the water percolates slowly down, and the water that enters aquifers is generally of good drinking quality.

References

- Bauer, A., and A.L. Black. 1994. Quantification of the effect of soil organic matter content on soil productivity. *Soil Science Society of America, Journal* 58:185-193.
- Bull, L., H. Delvo, C. Sandretto, B.L. Mood. 1993. Analysis of pesticide use by tillage systems in 1990, 1991, 1992 corn and soybeans. *Agricultural Resources: Inputs AR-32*. USDA, Economic Research Service.
- Edwards, J.N., C.W. Wood, D.L. Thurlow, and M.E. Ruff. 1992. Tillage and crop rotation effects on fertility status of a hapludult soil. *Soil Science Society of America, Journal* 56:1577-1582.
- Edwards, W.M., M.J. Shipitalo, and L.D. Norton. 1988. Contribution of macroporosity to infiltration into a continuous corn no-tilled watershed: implications for contaminant movement. *Journal of Contaminant Hydrology* 3:193-205.
- Kunishi, H.M., V.A. Bandel, and F.R. Mulford. 1986. Seasonal uptake of P by corn under no-till and conventional till management. *Communications in Soil Science and Plant Analysis* 17:591-600.
- Lindstrom, M.J., F.E. Koehler, and R.I. Papendick. 1974. Tillage effects on fallow water storage in eastern Washington. *Agronomy Journal* 66:312-316.
- Lu, N., J.H. Edwards, R.H. Walter, and J.S. Bannon. 1994a. Organic wastes and nitrogen sources interacting on corn growth and yield. In Kenneth L. Campbell, Wendy D. Graham, and A.B. Botcher, eds., *Proceedings of the Second Conference on Environmentally Sound Agriculture*, pp. 431-438. American Society of Agricultural Engineers, St. Joseph, MI.
- Lu, N., J.H. Edwards, R.H. Walter, and J.S. Bannon. 1994b. Organic wastes and nitrogen sources interaction on soil solution ionic activity. In *Compost Science Utilization* 3. J.G. Press, Emmaus, PA. In press.
- Norton, L.D., and S.L. Schroeder. 1987. The effects of various cultivation methods on soil loss: a micromorphological approach. In N. Federoff, L.M. Bresson, and M.A. Courty, eds. *Soil Micromorphology*, pp. 431-436. French Association for the Study of Soils, Plaisir, France.
- Odell, R.T., W.M. Walker, L.V. Boone, and M.G. Oldham. 1984. *The Morrow plots: a century of learning*. University of Illinois, Agricultural Experiment Station Bulletin 775.
- Rasmussen, P.E., P. Collins, and R.W. Smiley. 1989. Long-term management effects on soil productivity and crop yield in semi-arid regions of eastern Oregon. *Oregon State University Bulletin* No. 675.
- Reicosky, D.C., and M.J. Lindstrom. 1993. Fall tillage method: effect on short-term carbon dioxide flux from soil. *Agronomy Journal* 85:1237-1243.
- Sumner, M.E. 1990. Gypsum as an ameliorant for the subsoil acidity syndrome. Report submitted to the Florida Institute of Phosphate Research by the Agronomy Department, University of Georgia, Athens.
- Wang, J., J.D. Hesketh, and J.T. Wooley. 1986. Preexisting channels and soybean rooting patterns. *Soil Science* 141:432-437.

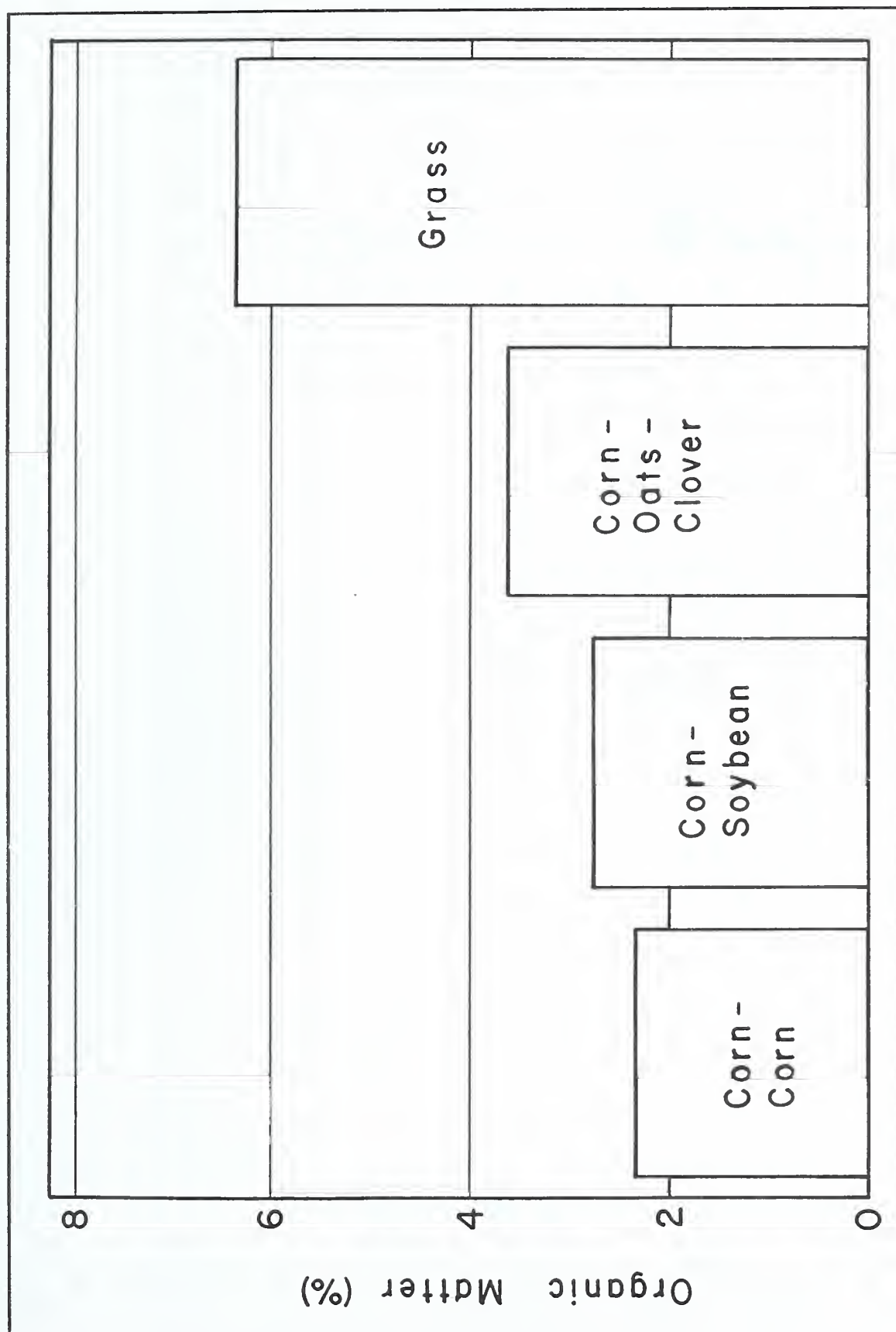


Figure 12. Percentage of organic matter in plowed soils after more than 100 years in various rotations compared with percentage in untilled soil still in grass. Source: Odell et al. 1984.

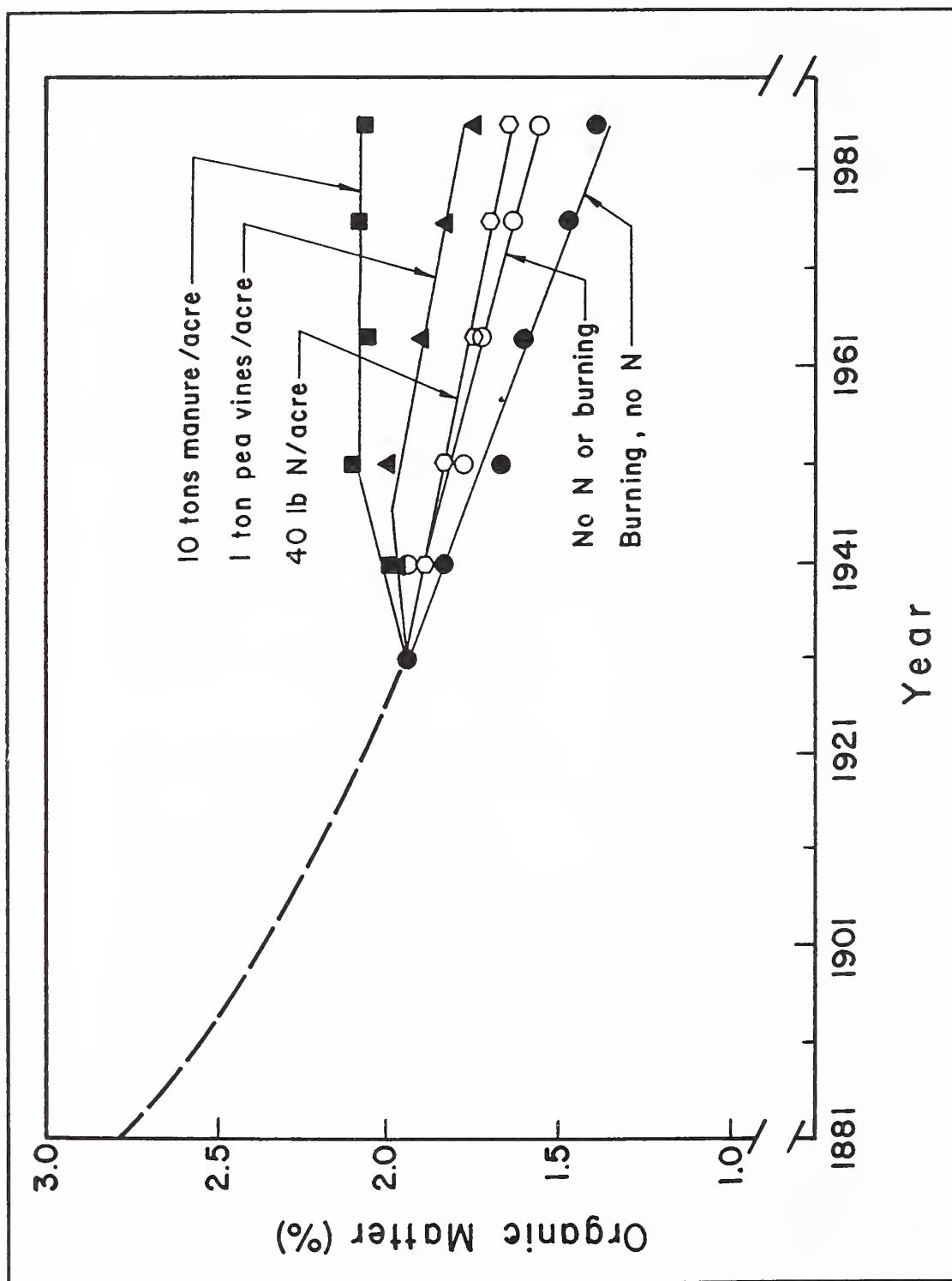


Figure 13. The effect of management practices on long-term changes in organic matter in the top 30 cm of a Haploxeroll soil in Oregon. Source: Rasmussen et al. 1989.

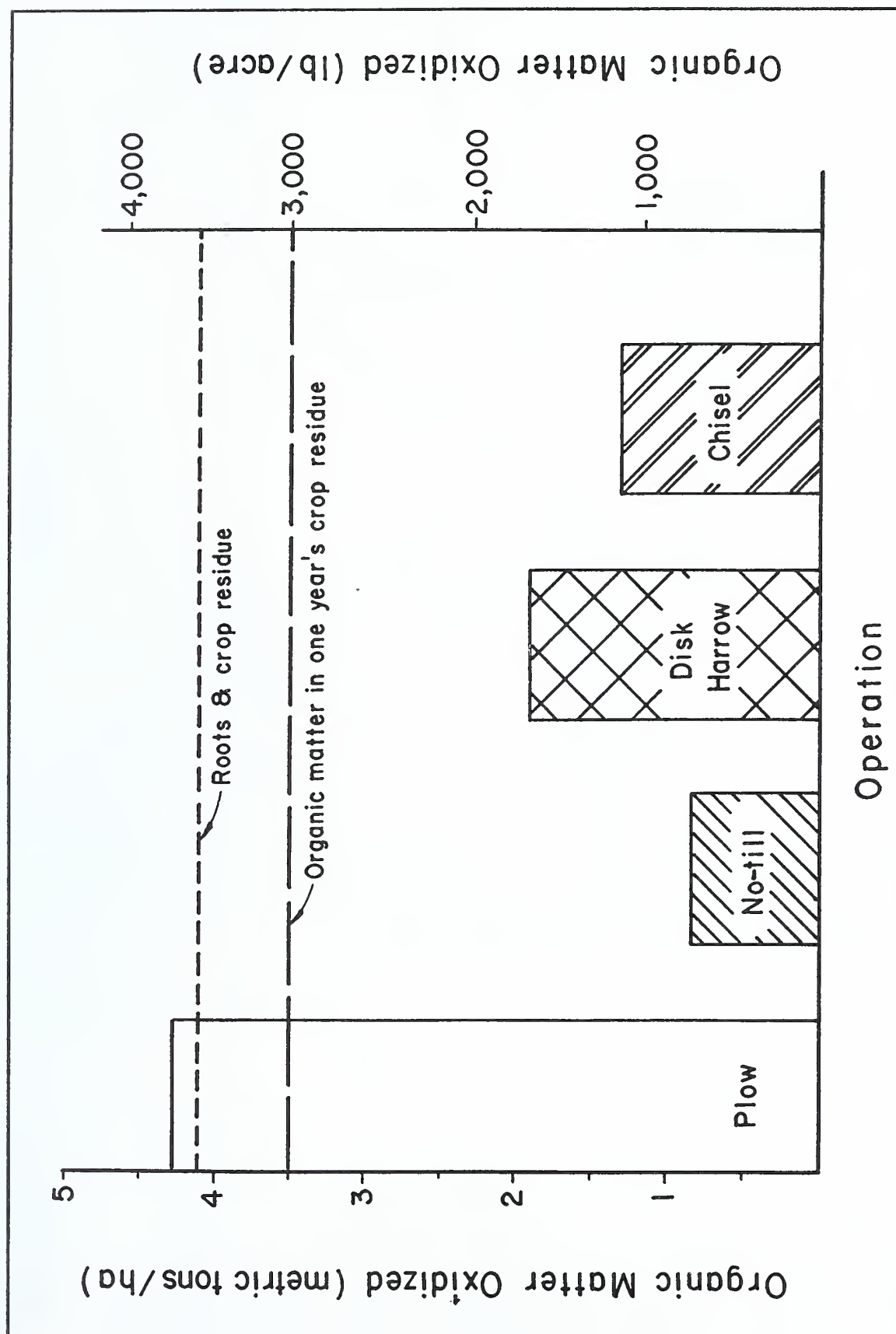


Figure 14. Organic matter oxidized in 19 days in September following various tillage operations on wheat stubble in Morris, MN.
Source: Reicosky and Lindstrom 1993.

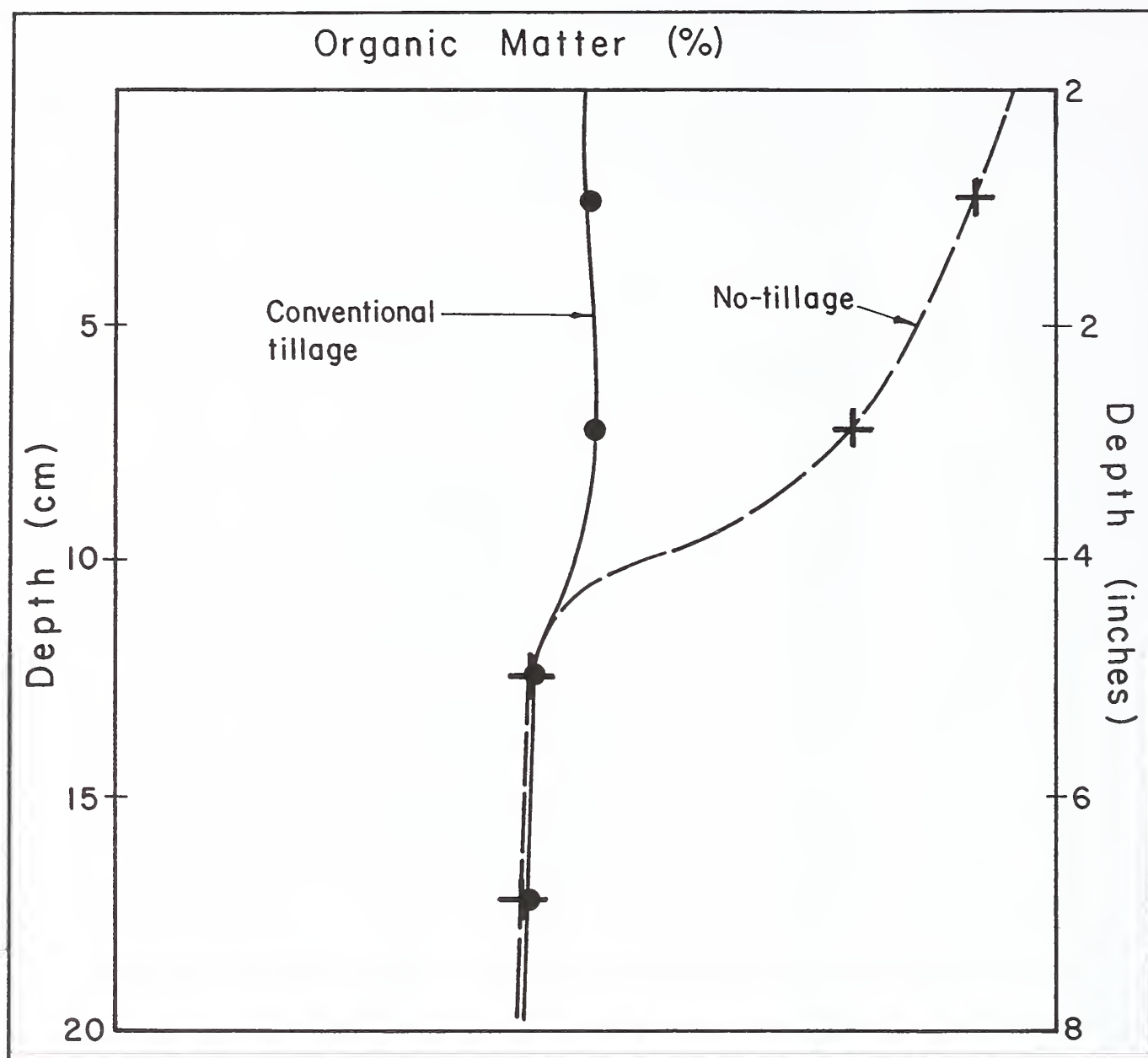


Figure 15. Comparison of organic matter content at various soil depths after 10 years of a conventionally tilled and a no-tilled corn-wheat-soybean-wheat rotation in Crossville, AL. Source: Edwards et al. 1992.

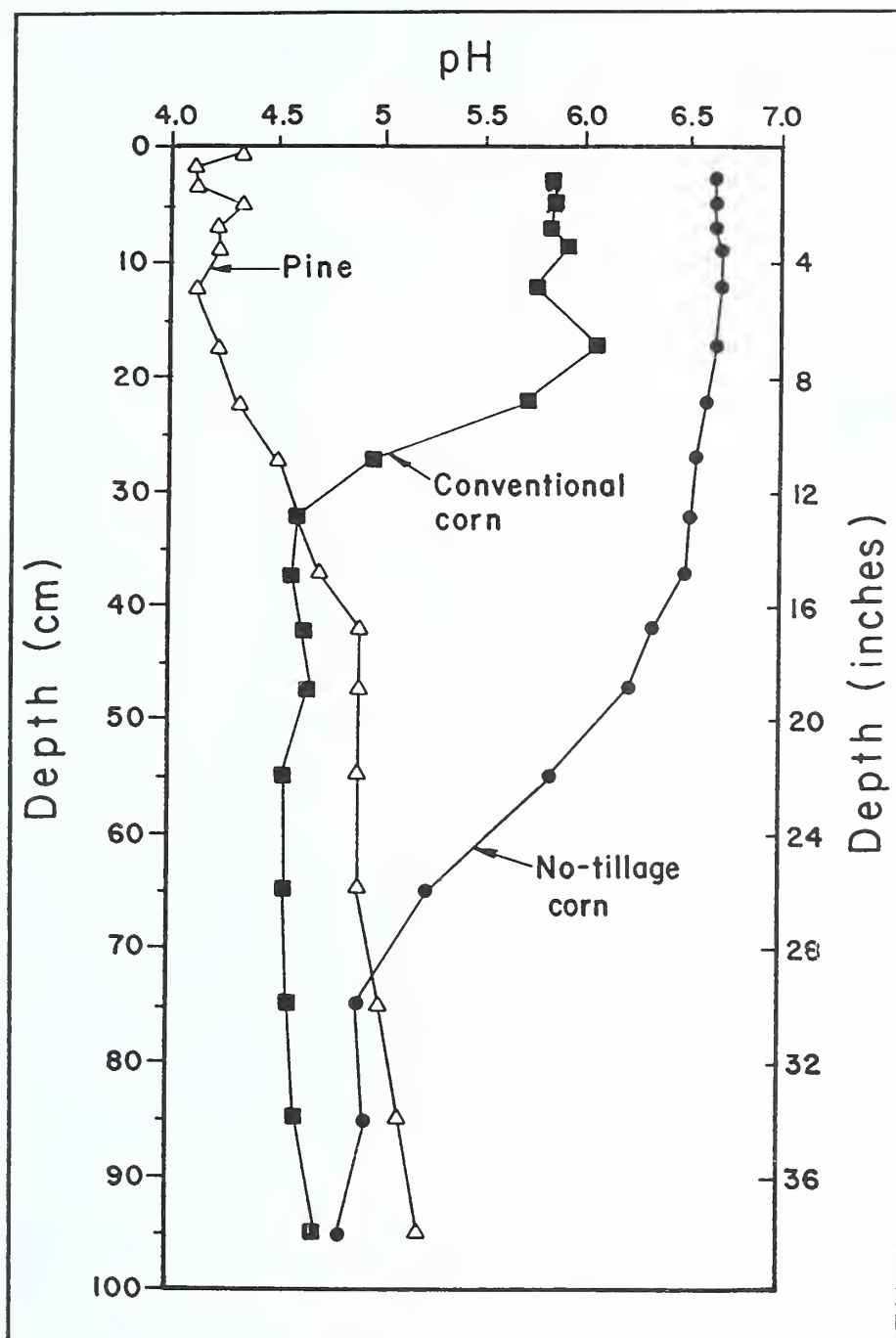


Figure 16. The effect of conventional and no-till management of corn on soil pH at various depths. Source: Edwards et al. 1988.

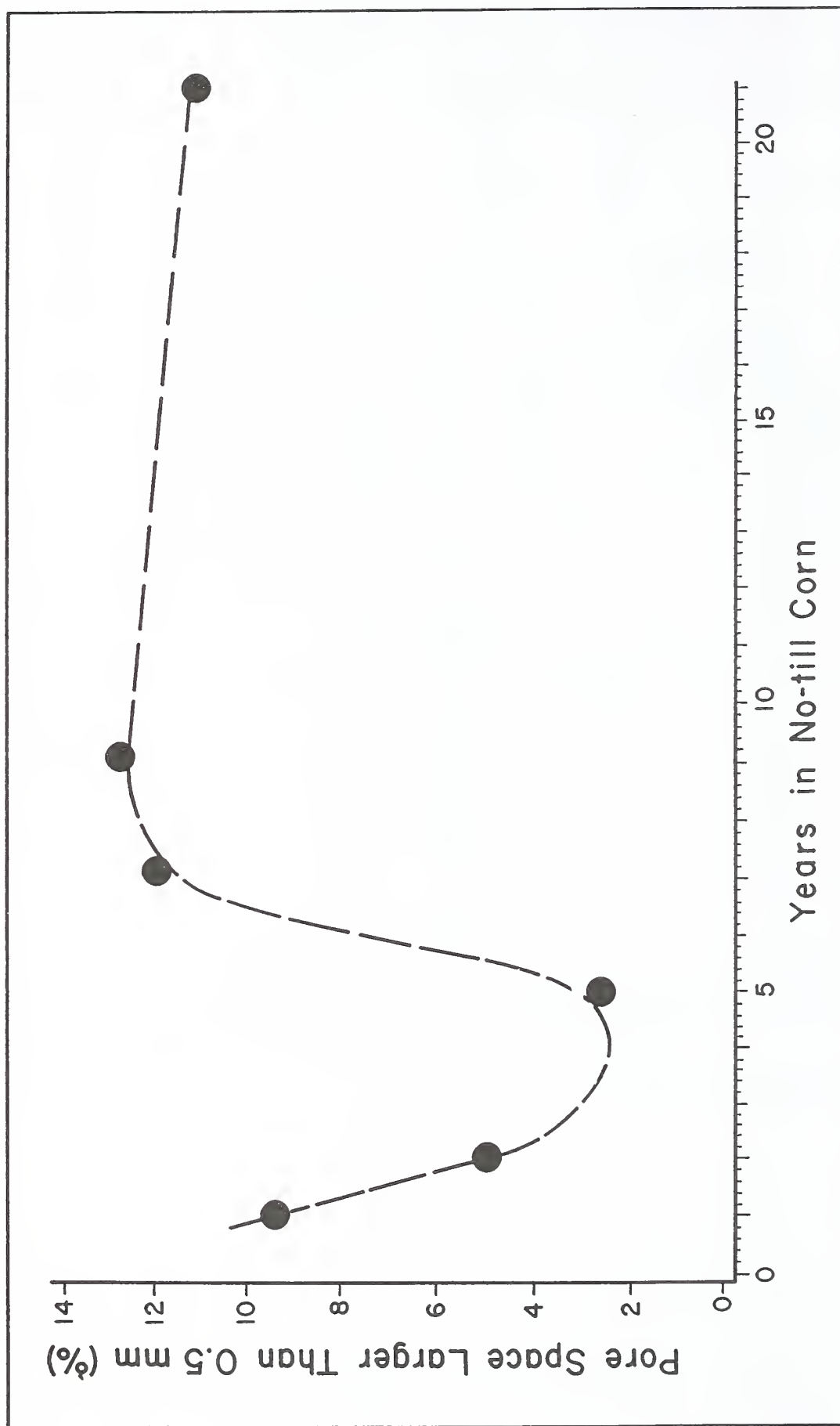


Figure 17. Changes in surface pores larger than 0.5 mm diameter after beginning no-till management in Coshocton, OH. Source: Norton and Schroeder 1987.

16 Management Options After Leaving the Conservation Reserve Program

T.E. Schumacher, M.J. Lindstrom, M.L. Blecha, and B.A. Stewart

A critical question for land managers enrolled in the USDA Conservation Reserve Program (CRP) is how to retain the benefits derived from the CRP once their contracts with USDA expire. This chapter describes the CRP, how grass affects soil properties, and post-CRP management options, including no-till.

The Conservation Reserve Program

The Conservation Reserve Program was initiated in 1985 under the Food Security Act with the intention of converting up to 45 million acres (18 million ha) of highly erodible farmland to permanent ground cover. The rationales for implementing the program included controlling erosion, raising farm prices, protecting wildlife habitats, and improving the national budget. Most of the land enrolled in the CRP was potentially highly erodible or was already eroding at an excessive level.

Under the program USDA pays participants an annual rent for 10 years plus half the cost of establishing a conserving land cover. Conditions of the program require landowners to enroll part of their land in CRP and then to relinquish an equivalent portion of their claim to "base acreage" on which the Federal Government commits to supporting the commodities price. This relinquished base acreage will be returned when acres come out of the CRP. The objectives of the CRP have changed over the course of the program and new procedures were developed for selecting lands proposed for the program.

Since 1985, 8 percent of U.S. cropland comprising 36.4 million acres has been enrolled in the CRP. The first contracts will expire in 1995, and by 1997 contracts on 24 million acres will expire. Fifty-five percent of the CRP acres (20 million acres) are located in the 10 Great Plains states. Commodity-crop base acreage was reduced by 23.3 million acres, and erosion was reduced by about 19 tons/acre/yr on average.

As their contracts approach expiration, producers are questioning what the future holds for their enrolled land. Many of the lands in the program previously suffered considerable erosion and structural deterioration. Soil structure has greatly improved because these lands have been retained in grass, but these improvements will be rapidly lost if the lands are tilled. However, landowners can maintain the environmental benefits from the CRP, even on land returning to crop production, if they select the appropriate options.

Among the available choices are leaving the acres in grass for hay or livestock production, establishing wildlife and recreation enterprises, or returning all or part of the land to crop production. Most farmers polled by the Soil and Water Conservation Society, Ankeny, IA, indicated economic necessity would force them to begin production agriculture when their CRP payments stop.

How Grass Benefits Soil

The structure of any given soil texture influences the size, distribution, and geometric arrangement of the pores within the soil. The properties of the pores determine such characteristics as water storage, plant-water availability, infiltration, internal drainage, and aeration. These characteristics often function at near optimal levels under a sod cover. Soils in the United States with the best aggregates for crop growth are those which have been in grass for many years. They have more organic matter, structural stability, total pore space, and air-filled pore space, as well as higher hydraulic conductivity and infiltration rates than conventionally tilled soils. Soils of long-term grasslands tend to have more pores in the size range that permits crops to extract the water than cropped soils. Earthworm channels connected to the surface reduce runoff and improve infiltration into the root zone, and populations of earthworms have been observed to be six to nine times higher in established grasslands than in cultivated soils.

Soils in long-term grass also show improved mechanical properties, allowing traffic under wetter conditions. Farmers who return fine-textured soils to tillage after a long period in grass observe that the time between the soils' being too wet to till and too dry to till decreases with each year of tillage.

Soil aggregates from North American virgin grasslands are more stable than their cultivated counterparts. Cultivation appears to cause a loss of particulate organic matter that binds microaggregates into macroaggregates. Particulate organic matter, which consists primarily of partially decomposed residue and roots, has a higher decomposition rate than other forms of organic matter, and its maintenance requires frequent additions to the soil. Soils under long-term cultivation return less root organic matter than do virgin grasslands, and this reduction appears to lower the organic carbon and nitrogen as deep as 18 inches below the tilled zone (Bauer and Black 1981). Grasses that form a sod cover, on the other hand, provide an excellent source of particulate organic matter.

In cultivated soils, organic carbon and nitrogen decrease most rapidly in the tilled zone during the first 10 years and then more gradually depending on the cropping system and climate (Bauer and Black 1981, Ismail et al. 1994). The pace of this change parallels that in soil structure, which deteriorates most rapidly in the first 2-3 years after cultivation.

The effects of tillage on soil properties are tied to soil type. For example, cultivation of sand dunes and newly deposited sediments low in organic matter, when coupled with adequate provision of crop nutrients and water, can produce reasonably good crops. When residues of grain crops are all returned to the soil, organic matter content can increase and physical properties can improve. In general, however, tillage degrades mature soils that have substantial organic matter content and good aggregation. Long-term tillage in these soils reduces water availability and aeration within the root zone. Pores containing water near field capacity were reduced 14 percent after 12 years of tillage on the Crowley soil in Arkansas (Scott and Wood 1989).

Finally, grass protects the soil surface from the impact of raindrops and from runoff by temporarily trapping water in surface microcatchments and allowing development of cracks and pores open to the surface.

Just as tillage degrades soils, soil structure improves when cropped land is planted in grass, with significant improvement observed in as little as 3–4 years. More time is required for restoration of soil properties to those found in virgin soil. Mazurak and Ramig (1962) estimated that grass provided its maximum benefits after 10–12 years in a medium-textured soil in Nebraska. Soil aggregate distribution, stability, air permeability, and hydraulic conductivity improved with time in the grass treatments. In a Canadian study the estimated half-life for net improvement in structural stability after the introduction of forage ranged from 4.5 years in a clay loam to 7.8 years in a sandy loam (Rasiah and Kay 1994). A review by Kay (1990) suggests that grass significantly improves soil structural stability for at least 10 years, and then improvements continue more slowly.

How the grass is managed influences its effects on soil properties. Harvesting hay slows changes in soil structure, and haying will reduce most of the benefits brought to the soil nitrogen pool by the addition of a legume, such as alfalfa (Haas et al. 1976). Although haying may slow the effects of alfalfa and grass on soil structure, improvement does appear to continue, as shown by the increased organic carbon and soil aggregate stability evident after 5 years of growing alfalfa for hay.

The degree of soil improvement from 10 years of grass is likely to be soil and site dependent. As a rule of thumb, the greater the structural deterioration from past cultural practices the more likely that grass management will improve agronomically important characteristics. Rasiah and Kay (1994) found that soil structure regenerated more quickly in soils with higher levels of organic matter and other stabilizing materials at the time grass was introduced. As mentioned, soils in the CRP generally fit into the category of degraded soils and often fit the highly erodible classification. Highly eroded soils tend to have reduced productivity, degraded soil structure, lower organic matter, and less than ideal conditions for root growth.

When tilled, soils that were once deteriorated or that have less than ideal physical characteristics are likely to rapidly lose the benefits gained from CRP involvement. The surfaces of these soils are also more likely to seal, which reduces infiltration and increases water runoff and soil erosion. So, a critical concern for managers of post-CRP land is how to maintain or prolong the advantages gained from 10 years of grass production.

Post-CRP Options

The best environmental approach for CRP lands is to extend the contract for an additional 10 years, provided that option exists. Such an extension would maximize benefits to the soil and wildlife resources. But there are also other possible options, which are listed following:

Maintenance of Grass Cover

- Hay production managed to avoid disturbing nesting birds, by delaying the first cutting, for example.
- Rotational grazing timed so nesting birds are not disrupted and grass is not damaged.
- Wildlife management, such as development of fee-based hunting preserves.
- Contracting with the Federal Government for an annual fee to keep permanent vegetation on environmentally sensitive areas on a long-term or permanent basis.

Return to Cropping

- No-till into sod, using appropriate rotations to manage weeds, pests, and fertility without a dramatic increase in purchased inputs.
- Wide v-blade sweep to undercut sod, followed by no-till planting or minimum-till air-seeder methods of production.
- Moldboard or chisel plow to remove the initial residue, followed by no-till to maintain the surface residue of subsequent crops.
- Conventional tillage, with modification of the tillage system and rotation to fit any required conservation plan.
- Grass or grass-legume mixture or both rotated among fields or strips to reduce erosion rates or intercept eroding sediment.

Other than keeping the CRP tract in grass cover, no-till systems appear to provide the greatest potential for maintaining or enhancing benefits while maintaining crop productivity.

No-Till After CRP

Benefits

No-till should prolong or maintain most of the benefits from CRP grassland in row-crop and small-grain crop systems. As discussed in chapter 15, no-till slows the rapid mineralization of carbon and nitrogen that occurs with tillage (see pages 55–56 and 63). Lamb et al. (1985) determined the effects of tillage and crop residue management on soil organic nitrogen losses in wheat-fallow systems that had been in native grasses. After 12 years, nitrogen loss in the top 12 inches of soil was 3 percent for no-till, 8 percent for stubble mulch, and 19 percent for tillage (black fallow). Evaluation of organic carbon and nitrogen levels in Kentucky on land that had been in bluegrass sod showed approximately twice as much carbon and nitrogen in the surface soil layer of no-till corn after 10 years of production as in that of conventionally tilled corn (Blevins et al. 1983). The organic carbon and nitrogen levels did drop under both tillage systems; however, with the addition of heavy nitrogen and lime applications under no-till the levels could be maintained close to those of the bluegrass.

One of the first changes resulting from intensive tillage involves breaking the continuity of established soil pores. In a permanent pasture that had been lightly grazed, 4 years of cultivation to a depth of 4 inches completely disrupted the many water-transmitting macropores. This disturbance reduced preferential flow within the macropore network and altered the pathway of infiltrated water movement, thereby causing increased water runoff. In contrast, the macropore system remained intact with no-tillage (Chan and Mead 1989).

While the degrading effects of tillage on soil structure is well documented, less is known about the structural effects of no-till into sod. Since carbon and nitrogen mineralization are reduced with no-till, presumably the rate of structural decline would not be as great as it is with tillage. One would expect no-till into sod to slow the loss of structural stability since there is no disturbance of soil structure. While no-till does reduce the rate of structural degradation, especially at the soil surface, the soil may lose structural stability over time in either a tillage or no-tillage system if the carbon input from the crop roots is less than that from grass sod.

The exact degree to which no-till can prolong the benefits of grass is still an open question. It is known that no-till systems which produce abundant residues significantly improve the surface characteristics of previously tilled fields. This aspect alone would be expected to increase infiltration and reduce erosion. By providing optimum crop nutrients and through the use of cover crops, no-till adds carbon to the soil. A study in Kentucky found that organic carbon content was restored to that of a bluegrass sod after

20 years of fertilized no-till corn with a rye winter cover crop (Ismail et al. 1994). It took only one moldboard plowing, however, to eliminate the structural improvements achieved from 3 years of no-till (Kladivko et al. 1986).

Development of soil macropores that extend from the surface to deep within the root zone, that are open to the atmosphere, and that are protected by residue cover result in high infiltration rates and reduce water runoff and subsequent soil loss. Packer and Hamilton (1993) concluded that water runoff and soil loss was more directly related to destruction of macropore continuity from tillage than to increases in organic matter and aggregate stability from conservation tillage systems.

Management Tips

Beginning no-till on CRP land involves killing the grass. For spring-planted crops, cutting the grass, removing it for hay, and spraying the regrowth with a systemic herbicide the previous fall works satisfactorily in most situations. Special attention must be given to CRP regulations during the last year of the contract to avoid illegal operations; for example, haying and grazing before September 30th of the 10th contract year may not be allowed. If the grass is dormant or under stress (a situation that may occur in regions where water is limited in the fall), then a systemic herbicide will give poor control. In these cases it may be better to kill the grass before dormancy and treat the field as fallow until planting. If the grass residues are extremely heavy, it may become necessary to remove some as a hay crop or to chop it to facilitate proper operation of the planting equipment and make the regrowth accessible to herbicide treatment. Consult CRP regulations before such removal or chopping.

For fall-planted crops, it is desirable to remove or chop the grass the previous spring, spray with a systemic herbicide, and treat the field as fallow during the summer. In wheat-fallow production areas, it may be necessary to begin this process the previous fall before seeding winter wheat. If cutting is used, the mowed grass must be evenly distributed in no-till management. In situations where a combination of cool- and warm-season grass species are involved, two applications of systemic herbicides may be needed to catch the grasses in their nondormant periods.

Undercutting with a wide v-blade sweep may be useful in the Great Plains several months before fall seeding a winter crop. If systemic herbicides fail because of grass dormancy, tilling with a moldboard or chisel plow may be needed to prepare for the first crop before going to no-till. As has been noted previously, however, the use of primary tillage equipment will destroy most of the macropore continuity and a major part of the organic matter that accumulated in the soil during the CRP period. In arid regions where runoff is infrequent, destruction of macropore continuity and

consequent reduction of infiltration rates may not be a major concern. Under these conditions the use of undercutting tillage, which keeps most of the sod on the surface, is a reasonably good compromise.

Nitrogen management on CRP lands also needs special attention. As tillage decreases, microbial oxidation of organic matter decreases, so more organic nitrogen is retained in the soil. In Nebraska, total nitrogen concentrations in the upper 4 inches of soil decreased by 27 percent under no-till, 32 percent under stubble mulch, and 50 percent with moldboard plowing, compared to concentrations present under native sod (Follett and Schimel 1989).

Soil testing is critical. Soil fertility recommendations under no-tillage should factor in the effects of the 10-year period of grass and the lack of a primary tillage operation. No-till into sod will initially require higher nitrogen rates than moldboard plowing (Thomas et al. 1973).

Conservation Measures for Residue-Deficient Crops

When the primary cash crop produces little residue, such as cotton does, and the land is highly erodible from wind, there may not be sufficient residue during the year to provide the mandated erosion control. In such cases, the wind barriers discussed in chapter 8 can complement no-till management to achieve the needed control.

To significantly reduce wind velocity, the grass in these barriers should be stiff stemmed and tall, like switch grass or tall wheat grass. If grass on the CRP land is not stiff enough and tall enough to sufficiently reduce wind velocity, CRP rules allow the cover to be improved during the contract period. Most perennial grass species require about 2 years to reach full height and to get their roots below those of annual crops, so hedges of tall grass are more likely to thrive and protect crops if planted 1 or 2 years before the crops.

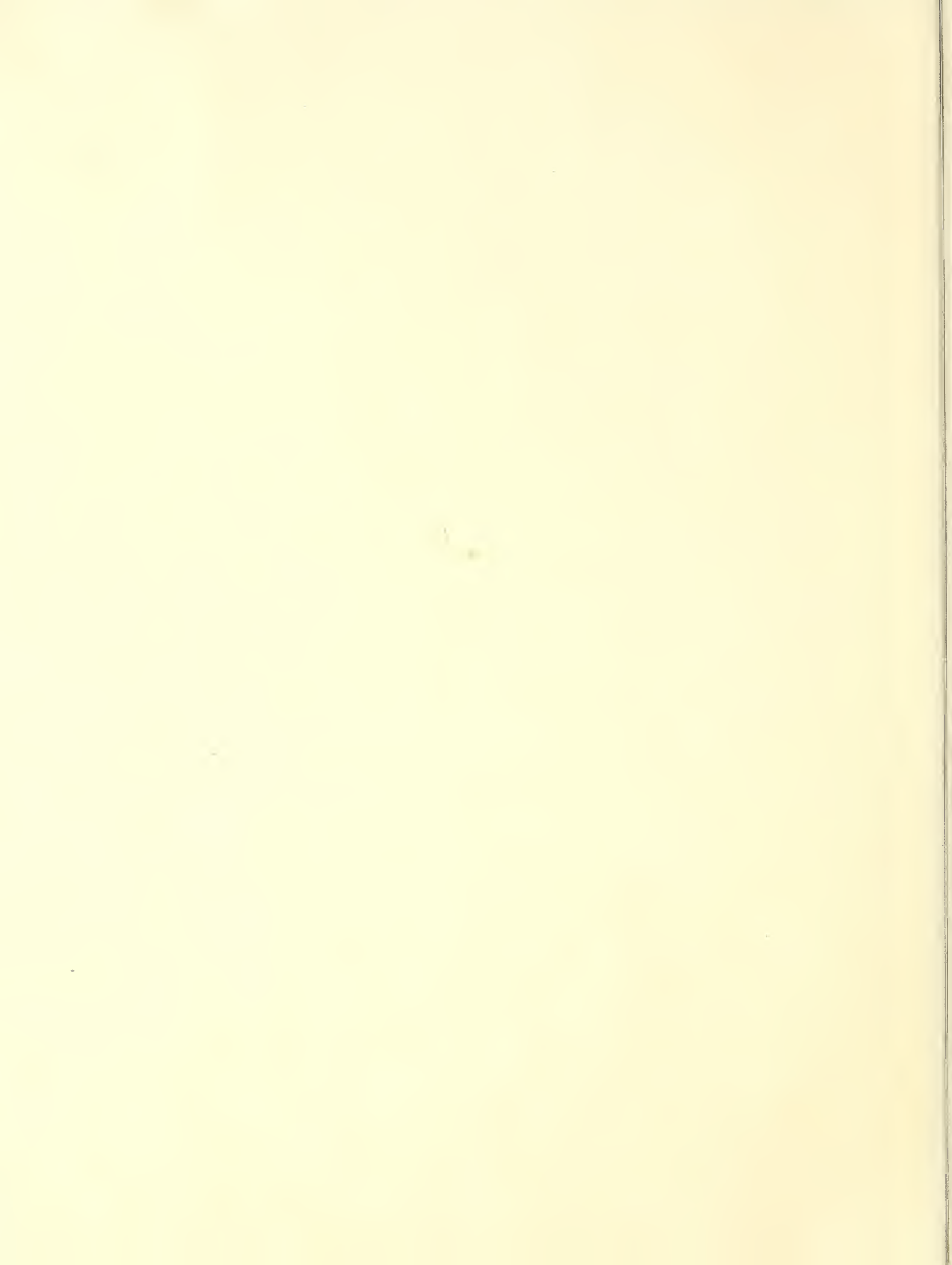
To plant the hedges, first kill the grass strips in the CRP land with herbicides and then sow these strips with the desired grasses. CRP contract rules permitting, the short grasses between the hedges may be killed when the hedges reach the desired height and in preparation for planting the crop. To avoid violating CRP rules, it is important to discuss all plans for installing tall grass hedges with your SCS District conservationist.

The CRP does not share the costs of controlling erosion with tall grass hedges on contract land, but the cost for herbicides and seed is small since less than 10 percent of any contract area can be in hedges.

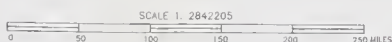
References

- Bauer, A., and A.L. Black. 1981. Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. *Soil Science Society of America, Journal* 45:1166-1170.
- Blevins, R.L., G.W. Thomas, M.S. Smith, et al. 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. *Soil Tillage Research* 3:135-146.
- Chan, K.Y., and J.A. Mead. 1989. Water movement and macroporosity of an Australian Alfisol under tillage and pasture conditions. *Soil Tillage Research* 14:301-310.
- Follett, R.F., and D.S. Schimel. 1989. Effect of tillage practices on microbial biomass dynamics. *Soil Science Society of America, Journal* 53:1091-1096.
- Haas, H.J., J.F. Power, and G.A. Reichman. 1976. Effect of crops and fertilizer on soil nitrogen, carbon, and water content, and on succeeding wheat yields and quality. U.S. Department of Agriculture ARS-NC 38.
- Ismail, I., R.L. Blevins, and W.W. Frye. 1994. Long-term no-tillage effects on soil properties and continuous corn yields. *Soil Science Society of America, Journal* 58:193-198.
- Kay, B.D. 1990. Rates of change of soil structure under different cropping systems. *Advances in Soil Science* 12:1-52.
- Kladivko, E.J., D.R. Griffith, and J.V. Mannering. 1986. Conservation tillage effects on soil properties and yield of corn and soya beans in Indiana. *Soil Tillage Research* 8:277-287.
- Lamb, J.A., G.A. Peterson, and C.A. Fenster. 1985. Wheat fallow tillage systems' effect on a newly cultivated grassland soils' nitrogen budget. *Soil Science Society of America, Journal* 49:352-356.
- Mazurak, A.P., and R.E. Ramig. 1962. Aggregation and air-water permeabilities in a chernozem soil cropped to perennial grasses and fallow-grain. *Soil Science* 94:151-157.
- Packer, I.J., and G.J. Hamilton. 1993. Soil physical and chemical changes due to tillage and their implications for erosion and productivity. *Soil Tillage Research* 27:327-339.
- Rasiah, V., and B.D. Kay. 1994. Characterizing the changes in aggregate stability subsequent to the introduction of forages. *Soil Science Society of America, Journal*. In press.
- Scott, H.D., and L.S. Wood. 1989. Impact of crop production on the physical status of a Typic Albaqualf. *Soil Science Society of America, Journal* 53:1819-1825.
- Thomas, G.W., R.L. Blevins, R.E. Phillips, and M.A. McMahon. 1973. Effect of a killed sod mulch on nitrate movement and corn yield. *Agronomy Journal* 65:736-739.





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